NREL
Transforming ENERGY

Workshop on Energy Planning Resources for Puerto Rico

San Juan | March 19, 2019

Mayaguez | March 22, 2019

8:30 a.m. – 4:30 p.m.

Agenda

- Welcome and Introductions
- Overview and Panel Discussion
- Break
- Presentations on Data and Tools
- Facilitated Discussion on Data, Tool, and Training Priorities
- Report-Out from Discussion
- Next Steps

Welcome and Introductions

- **Facilitators**
  - Dr. Elaine Ulrich, Senior Advisor, Solar Energy Technology Office, U.S. Department of Energy (DOE)
  - Robin Burton, Research Analyst, Strategic Energy Analysis Center, National Renewable Energy Laboratory (NREL)

- **Purpose**
  - Present stakeholders in energy sector planning in Puerto Rico – including utilities, regulators, policymakers, ratepayers, renewable energy developers, and community representatives – with existing tools, data, and modeling results that may be helpful to energy professionals in Puerto Rico
  - Collect feedback on desired and most useful tools and data to advance the transition of Puerto Rico’s energy system to a more reliable, secure, and affordable system

- **In Small Groups**
  - Name, affiliation, your goals for today
  - Choose one person to report out

SOLAR ENERGY
TECHNOLOGIES OFFICE
U.S. Department Of Energy

DOE Multi-Lab Modeling Phase II

Stakeholder workshop and training

Elaine Ulrich, Ph.D.
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Solar Energy Technologies Office

WHAT WE DO

The Solar Energy Technologies Office funds early-stage research and development in three technology areas: **photovoltaics**, **concentrating solar power**, and **systems integration** with the goal of improving the affordability, reliability, and performance of solar technologies on the grid.

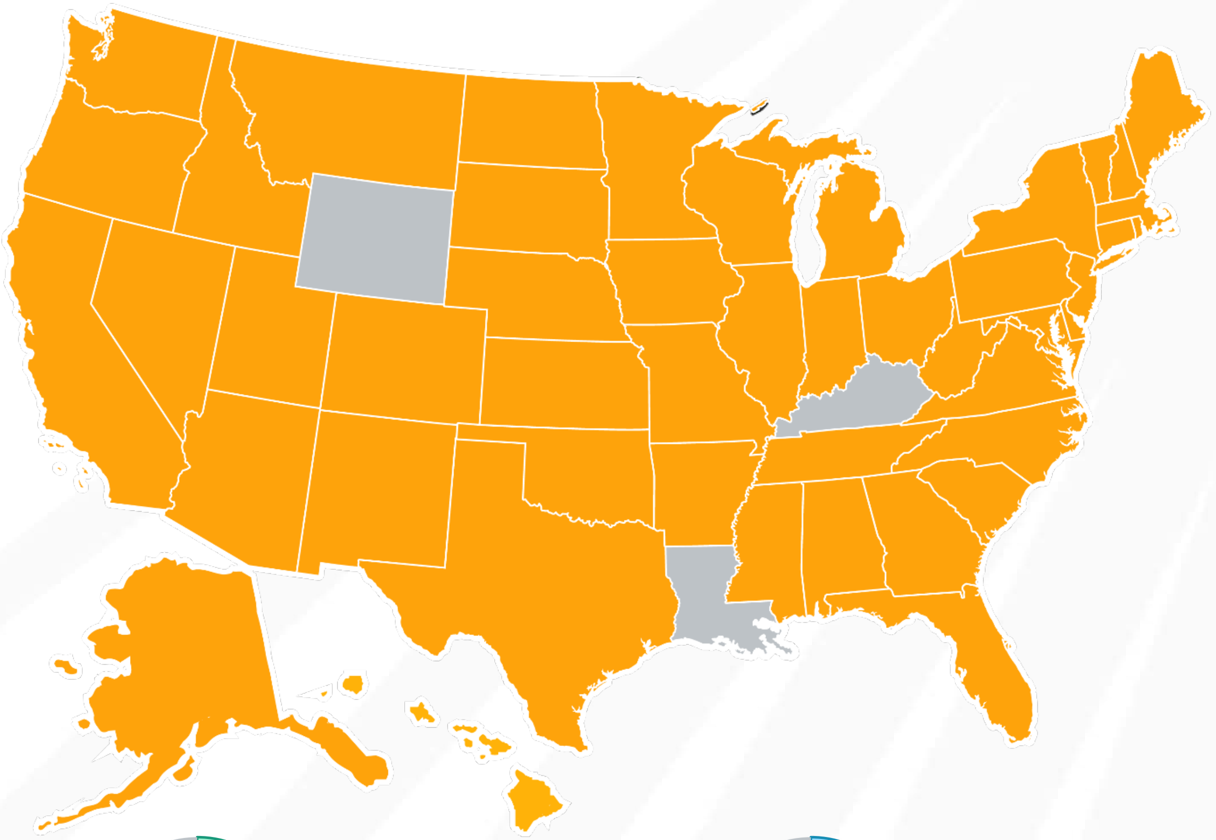
HOW WE DO IT

Cutting-edge **technology development** that drives U.S leadership and supports a growing and skilled workforce.

Research and development to **address integration of solar** to the nation's electricity grid.

Relevant and objective technical information on solar technologies to stakeholders and decision-makers.

DOE Solar Office Funds 300+ Active Projects



Projects and partners in **47 states** plus the **District of Columbia**

40% of projects at **national labs**

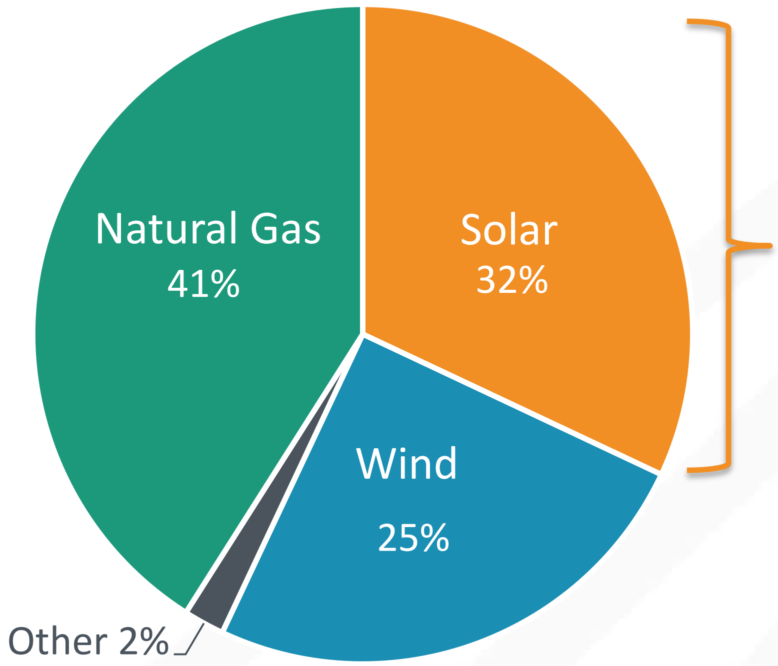
25% of projects with **universities**

35% of projects with **businesses & non-profits***

Note: SETO has funded past projects in Kentucky, Louisiana, and Wyoming.
*2% of state and local government

Solar is One of the Fastest Growing Energy Sources in America

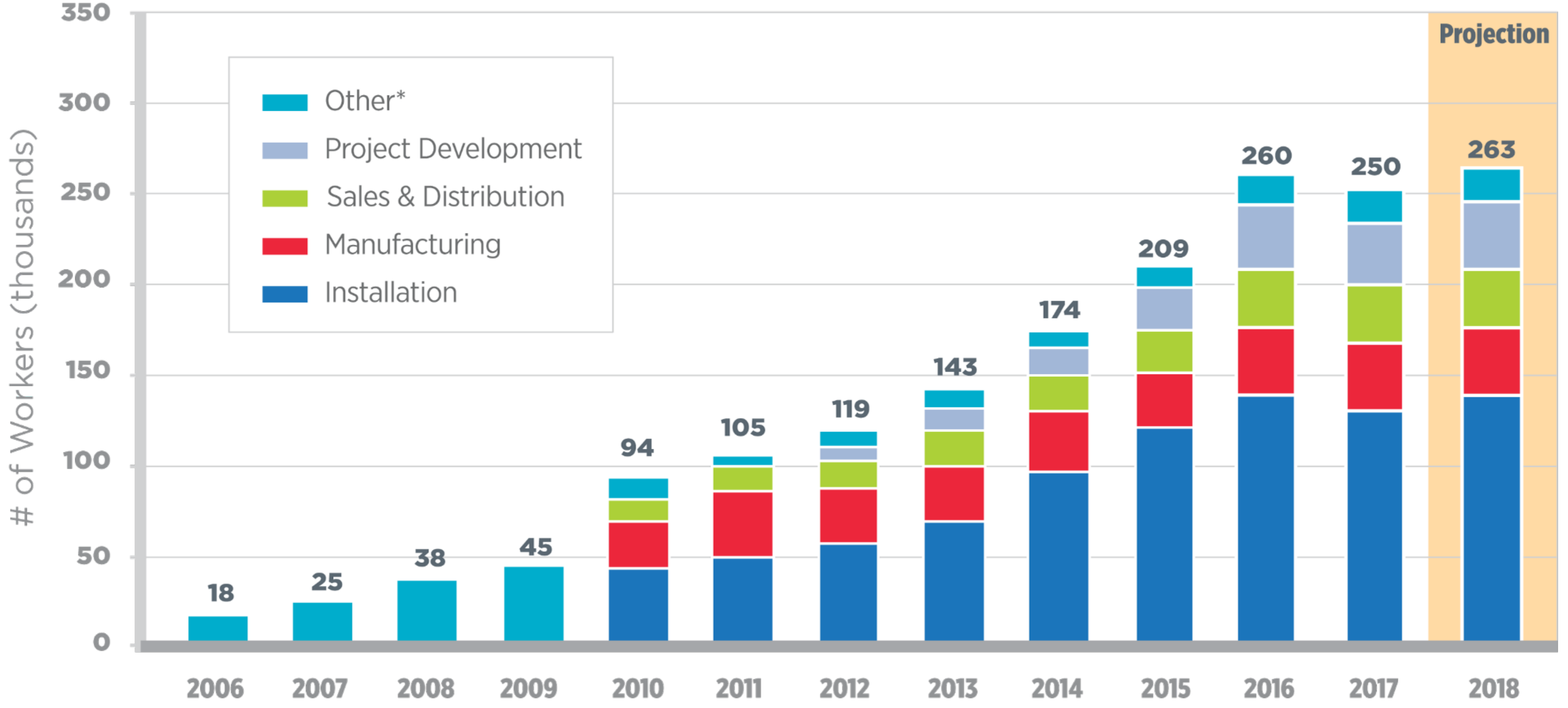
New Capacity Added in 2017



In 2017, solar PV represented **32%** of all new electricity capacity installed in the United States.

Solar energy represented **30%** of new capacity additions **over the past 5 years** and now supplies 2% of the nation's annual U.S. electricity.

250,000+ U.S. Jobs in the Solar Industry

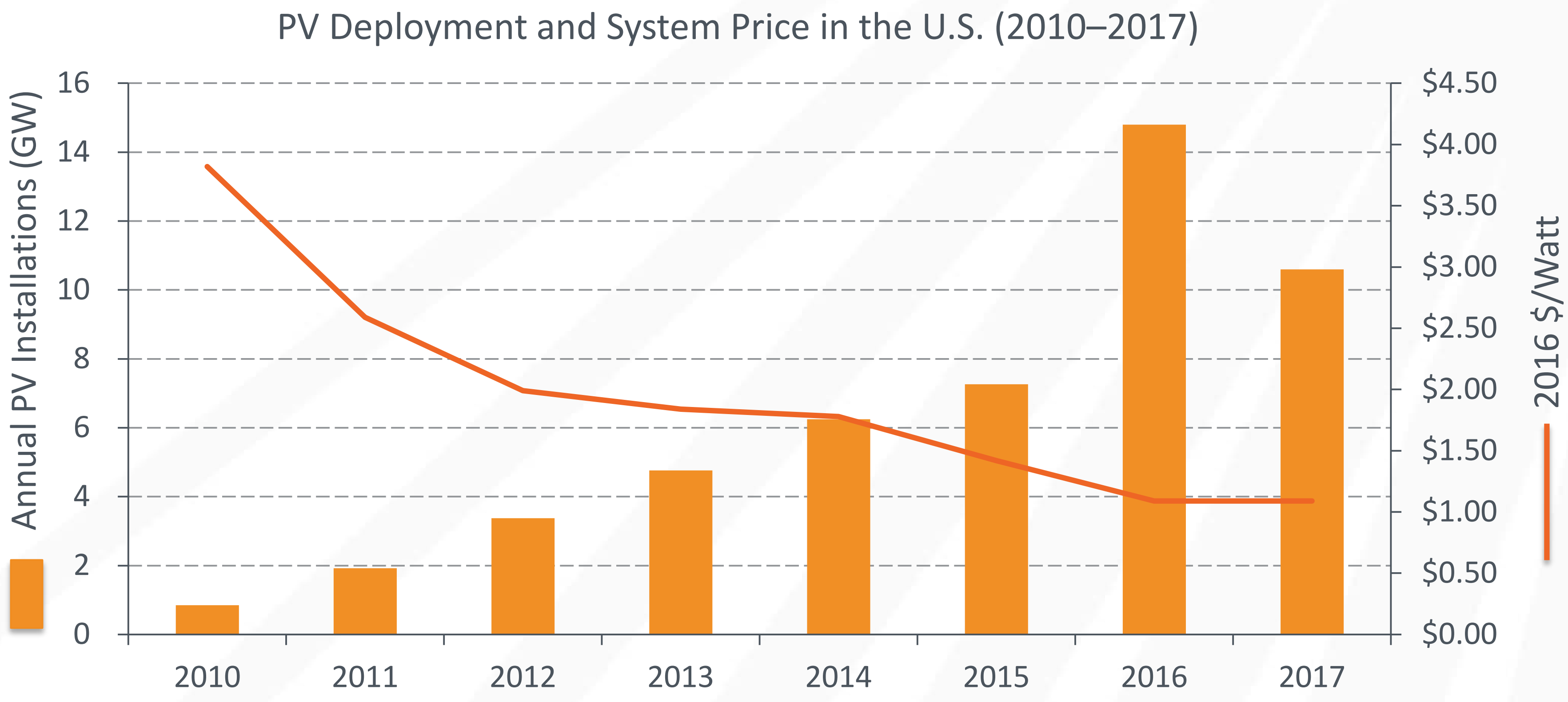


- Since 2010, solar employment **has grown by 168%**
- The median wage for solar installers is **$21 per hour,** increasing to **$30 per hour** for supervisors or foremen
- **9x** national job growth rate in the last 5 years
- **Manufacturing** is on the rise and is the **2nd largest sector** in the solar industry, growing **48%** since 2010

Source: The Solar Foundation, "2017 National Solar Jobs Census."

U.S. Solar: Falling Costs, Rising Deployment

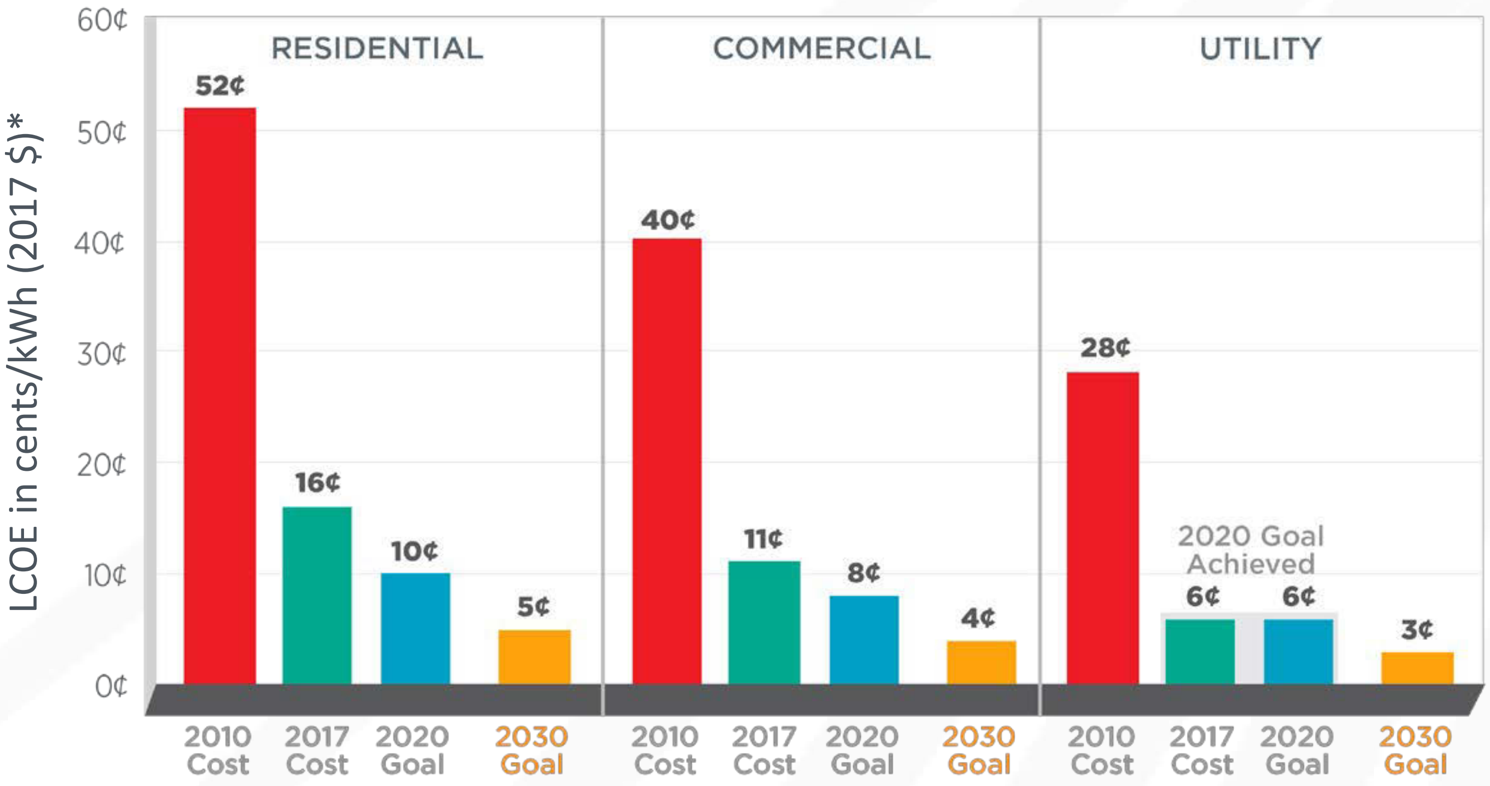
The solar energy industry is one of the fastest growing industries in the U.S. Driven by falling costs, total solar installed capacity is now **58.3 GW** with nearly **two million solar systems** operating across the country.



Sources: National Renewable Energy Laboratory, "U.S. Solar Photovoltaic System Cost Benchmark: Q1 2016"; GTM Research and SEIA, “U.S. Solar Market Insight Report: 2016 YIR."

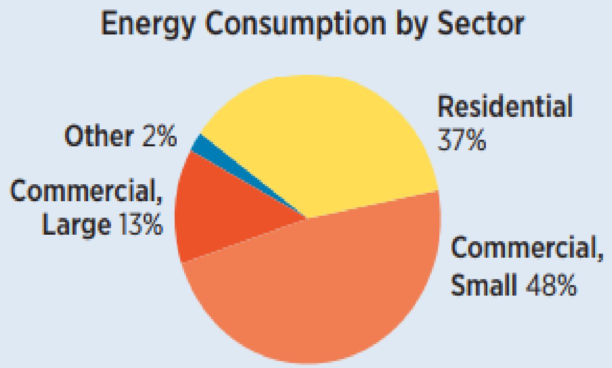
Progress and Goals: 2030 Photovoltaics Goals

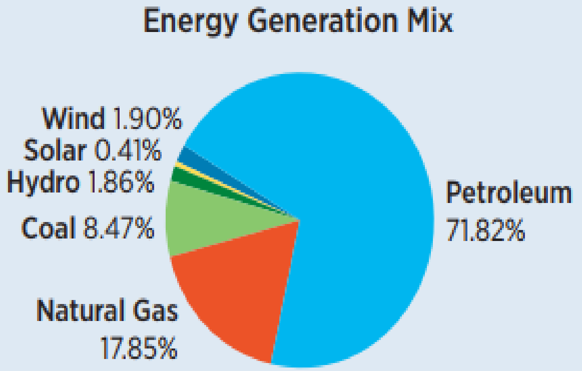
The office invests in innovative research efforts that securely integrate more solar energy into the grid, enhance the use and storage of solar energy, and lower solar electricity costs.



*Levelized cost of electricity (LCOE) progress and targets are calculated based on average U.S. climate and without the ITC or state/local incentives. The residential and commercial goals have been adjusted for inflation from 2010-17.

Puerto Rico Electricity Sector Overview

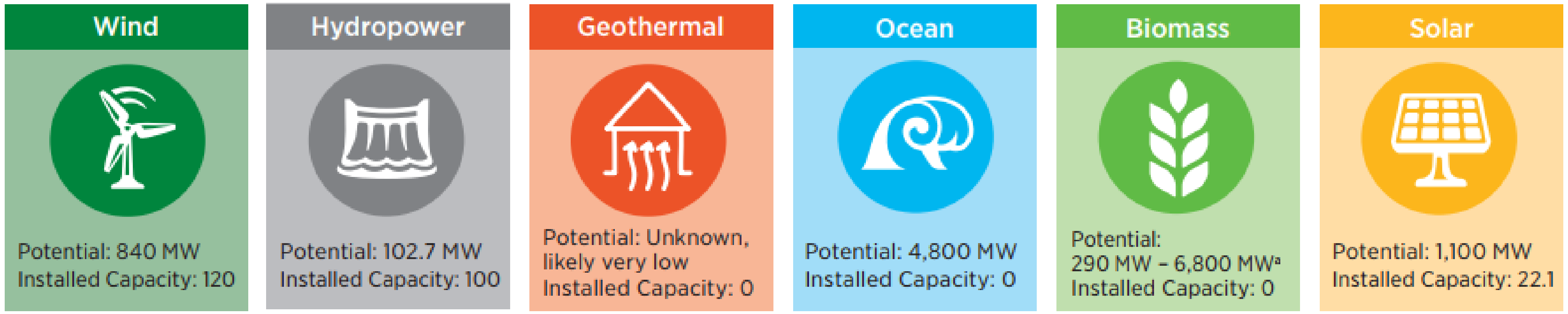




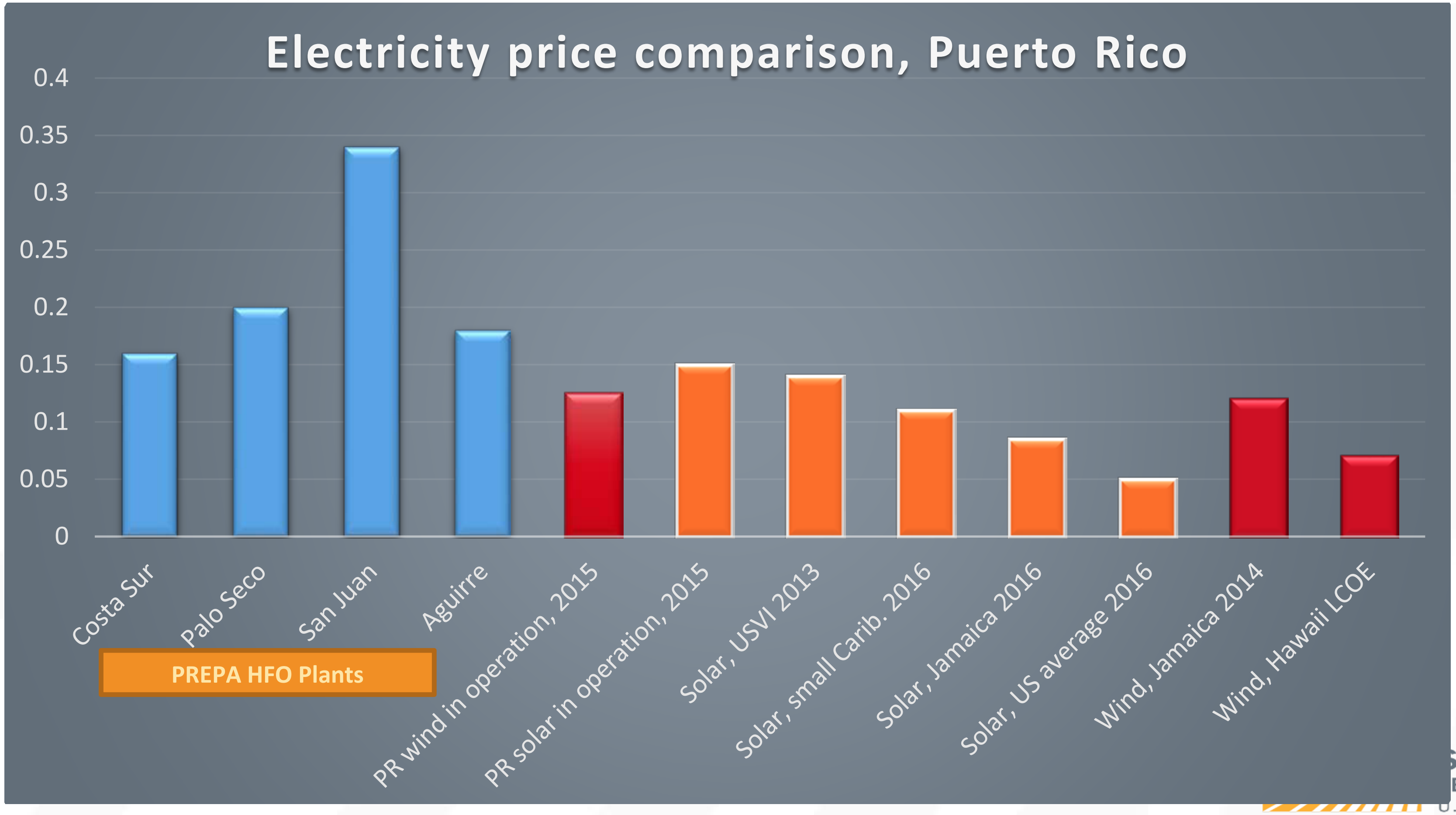
Total Installed Capacity	4,878 megawatts (MW) (PREPA) 961 MW (Power Purchase Agreements)	
Peak Demand	3,685 MW	
Total Generation	19,430 gigawatt-hours	
Renewable Share	4.2%	
Transmission & Distribution Losses	13.8%	
Electrification Rate	100%	
Average Electricity Tariffs (USD/kWh)	**Residential**	$0.25
	Commercial	$0.28
	Industrial	$0.24
	Public Authorities	$0.26
	Agriculture	$0.28
	Public Lighting	$0.42

NB: Most data from 2014-16

Renewable Energy Status and Potential



[a] The lower limit is traditional agricultural biomass, and the upper limit assumes that microalgae is commercially viable and in widespread use at maximum capacity.



Recent PR Grid Integration Work

"Advanced Grid-Friendly Controls Demonstration Project for Utility-Scale PV"

- National Renewable Energy Laboratory
- Funded by Solar Energy Technologies Office
- Conclusion: AES Ilumina PV (Guayama) plant can provide Automatic Generation Control, frequency response *faster than synchronous generators*, and voltage droop support to PREPA's grid, with existing hardware and proper communication protocols
- http://www.nrel.gov/docs/fy16osti/65368.pdf

Advanced Grid-Friendly Controls

Demonstration Project for Utility-Scale

Figure 32. Snapshot of PREPA's AGC units—no conventional units are selected.
Image from PREPA

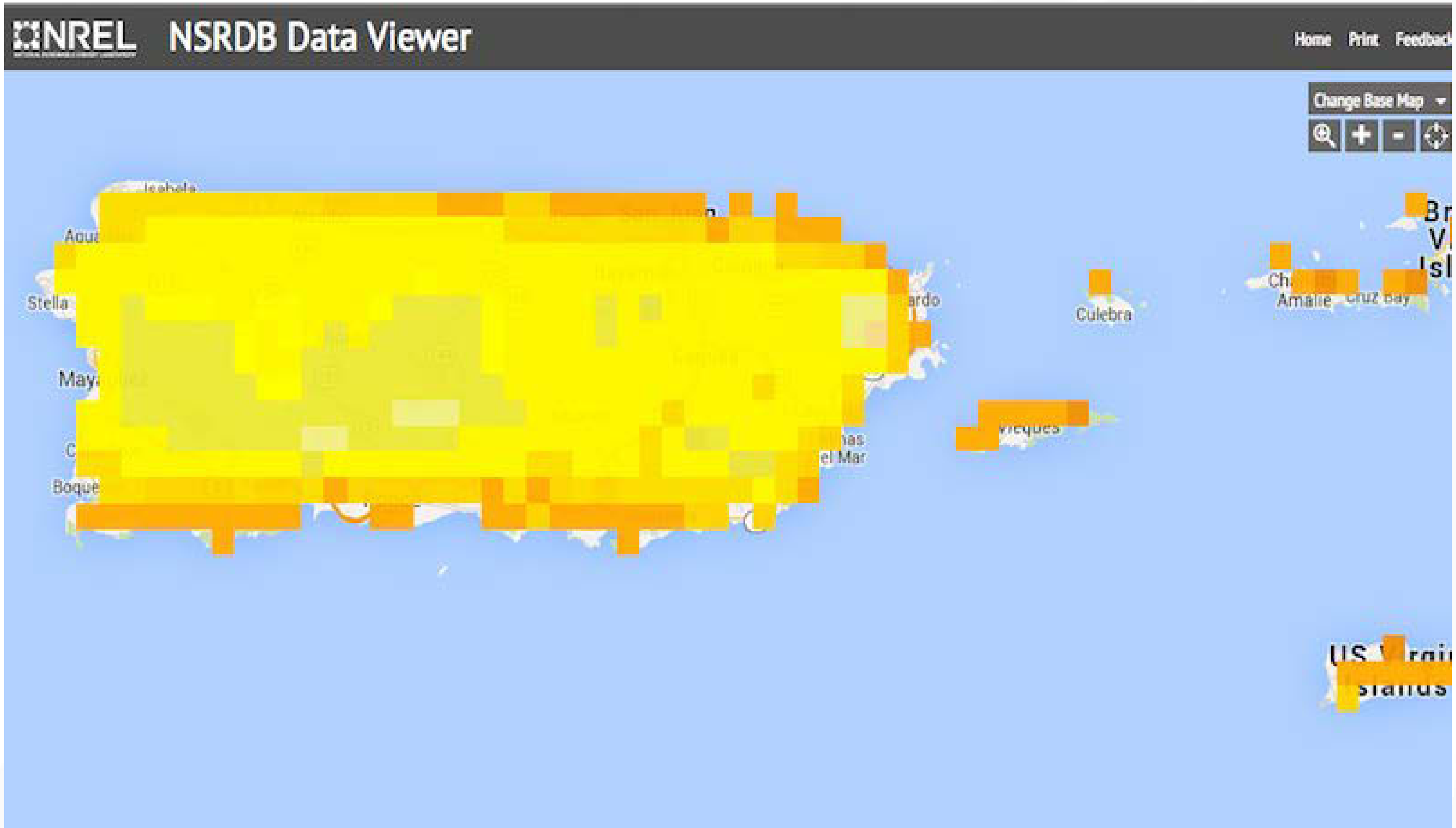
During a significant amount of the test period over a few days, AES PV was the only plant participating in AGC

Recent Hawaii PV Work

"Optimization of a Virtual Power Plant to Provide Frequency Support"

- Sandia National Laboratory
- Funded by Solar Energy Technology Office
- Conclusion: *Solar PV can reduce cost of grid operations* by reducing O&M of synchronous generators, even when compensating for curtailment ($20k/day savings using PV as reserves for FW22 on Lanai, Hawaii)
- http://prod.sandia.gov/techlib/access-control.cgi/2015/1511070r.pdf

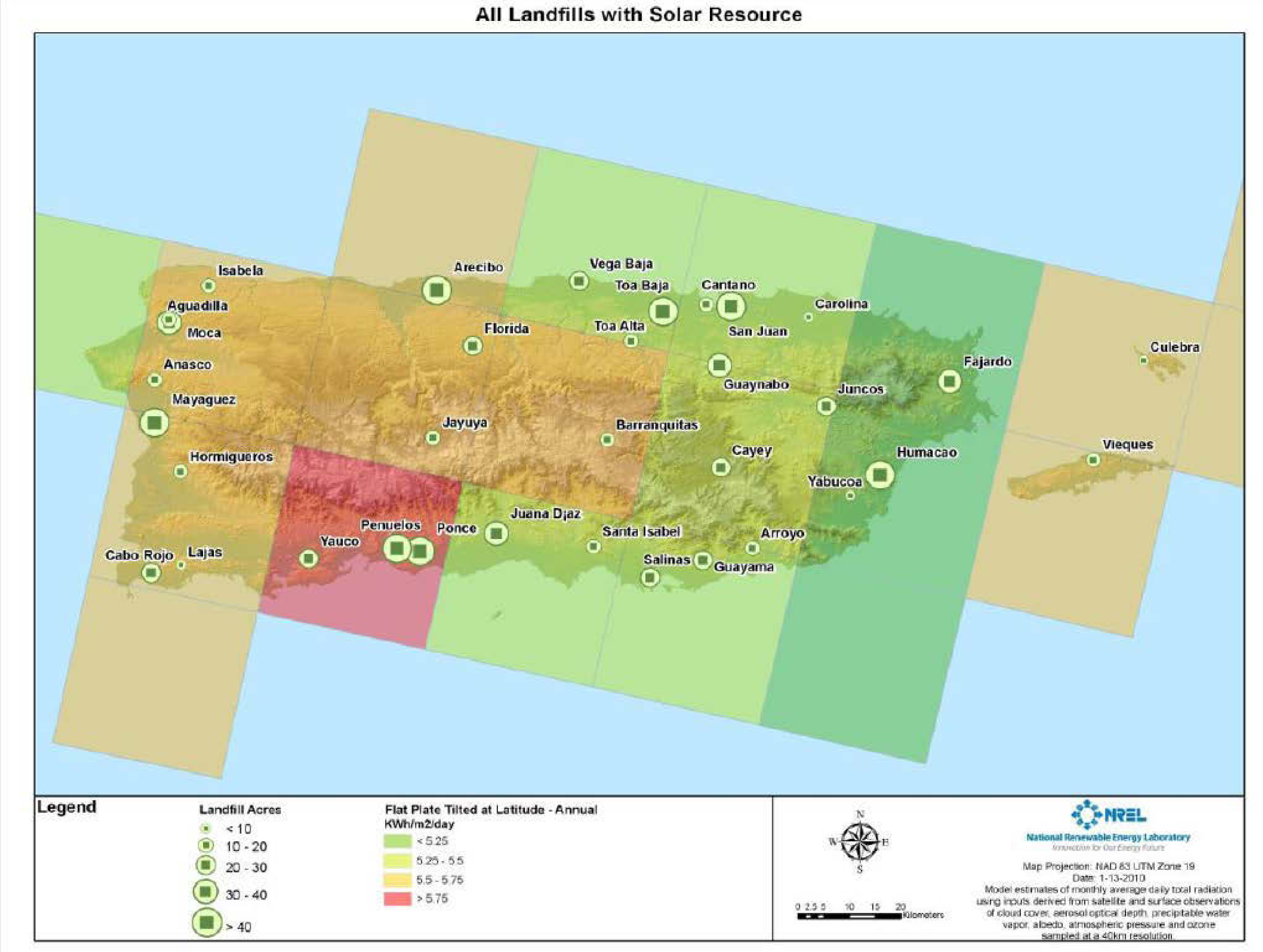
PR Solar Resource, v. 1



Most areas receive over 5 kWh/sq.m./day

NB: 4km resolution

PR Solar Resource, v. 2



Previous Work in Puerto Rico

"Review of PREPA Technical Requirements for Interconnecting Wind and Solar Generation"

- NREL, funded by EERE OSP
- Conclusion: Fourteen recommendations were made to PREPA regarding aligning its Mininum Technical Requirements (MTRs) with standard or best practice, not all followed.

"NGA Policy Academy on Targeting Clean Energy for Economic Development

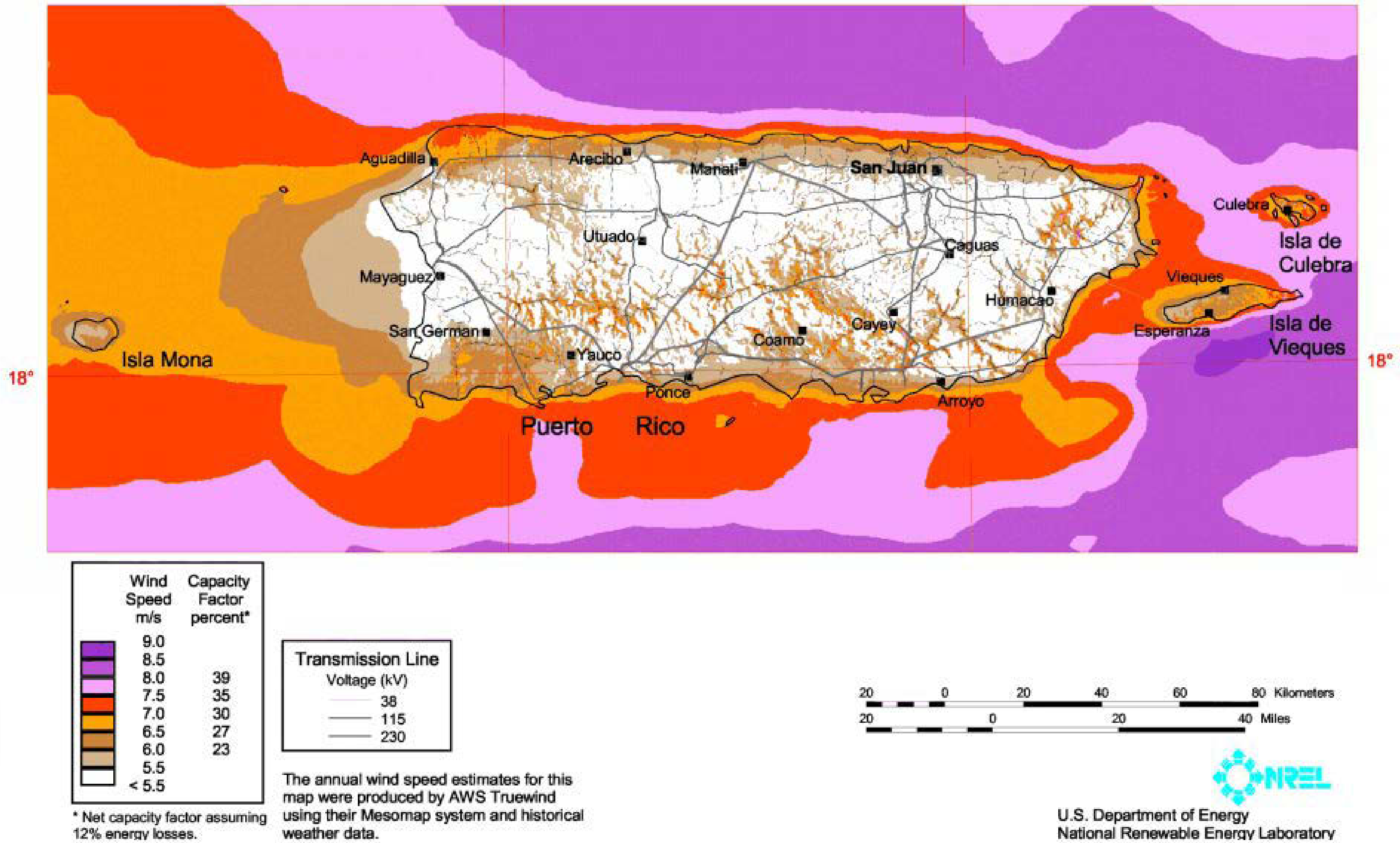
- Funded, primarily, by EERE OSP
- Conclusion: Resources were made available to Puerto Rico as Act 57 was drafted.

Previous Work in Puerto Rico

"Feasibility Study of Solar PV on Landfills in Puerto Rico"

- NREL, funded by EERE Intergovernmental Program Office (runs the State Energy Program)
- Conclusion: In 2011, Fifteen sites were evaluated for PV. Solid economics at PPA rates similar to AES Ilumina, if installation costs aligned with 2011 national average ($4/Watt).
  - 2015 National average was $3/AC-Watt, with some near $2
- http://www.nrel.gov/docs/fy11osti/52181.pdf
- http://www.nrel.gov/docs/fy11osti/49237.pdf

PR Wind Resource



PR Wind Background Info

- Two existing Wind IPP, ~$0.14/kWh, using economic resource on southern part of PR
- Low granularity map, https://windexchange.energy.gov/files/u/visualization/image/50m_VI.jpg
- Certain sites can be better than others, see e.g. St. Thomas https://www.nrel.gov/docs/fy15osti/63094.pdf

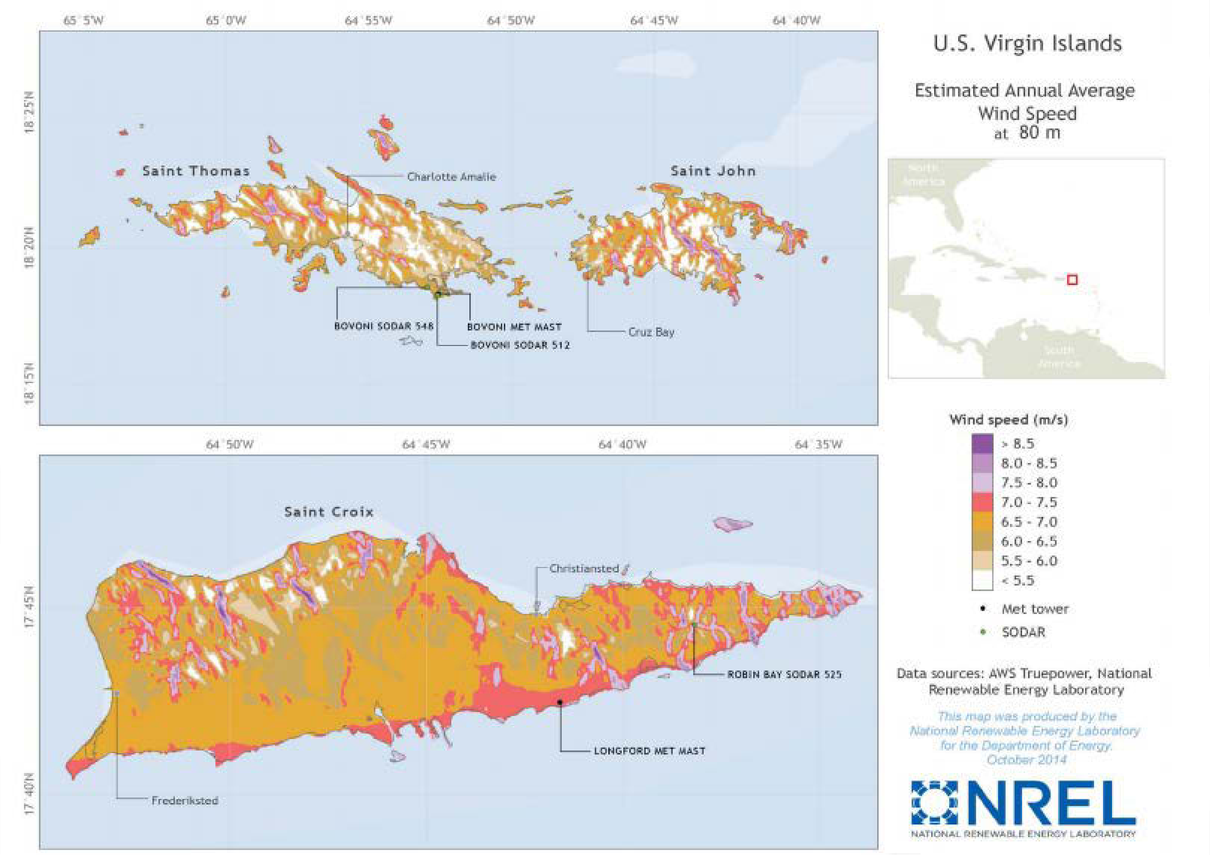


Figure 2. Estimated annual average wind speed at 80 meters

Landfill Gas, Waste-to-Energy

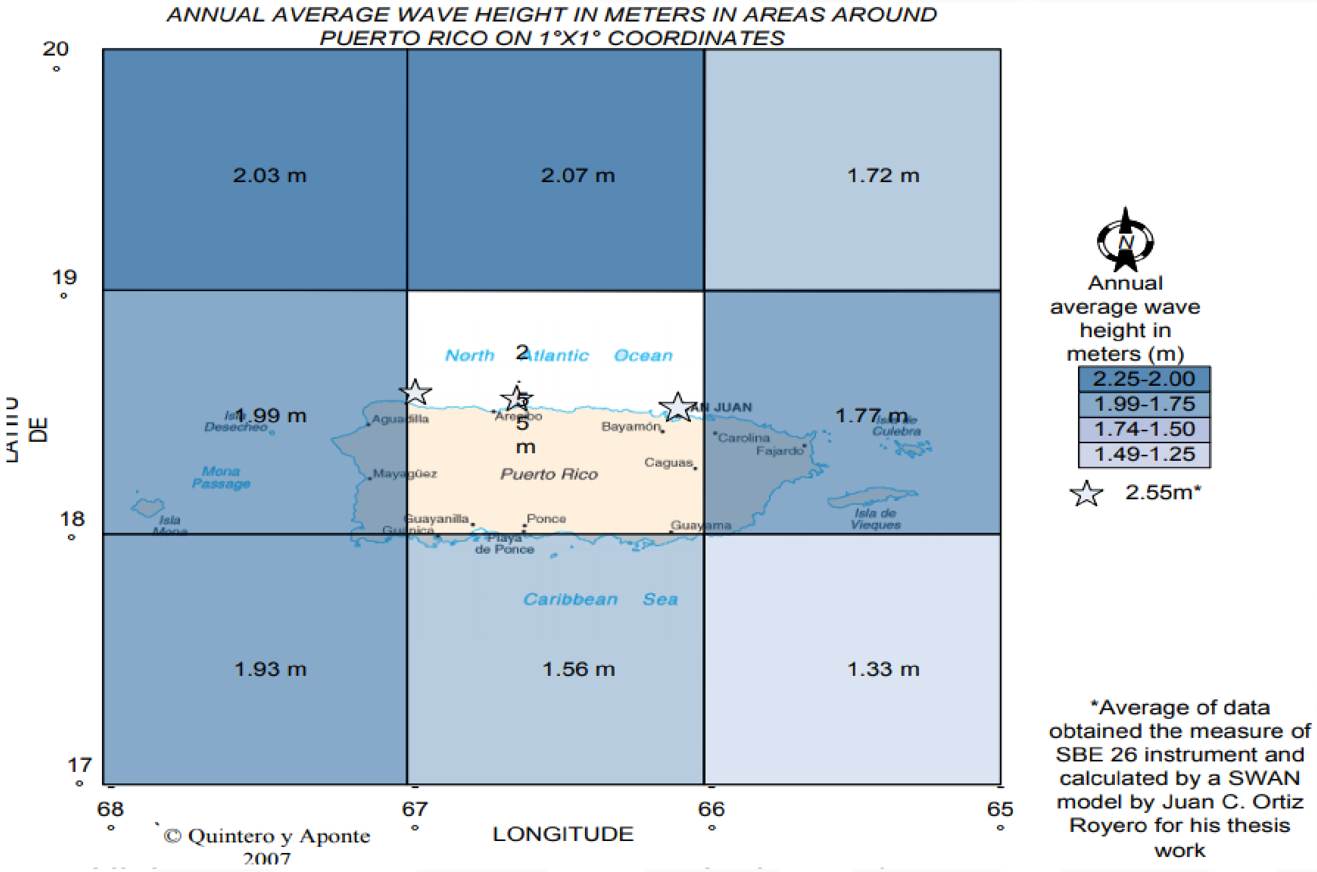
- EPA has ordered most landfills in PR to close, https://www.epa.gov/sites/production/files/2016-09/documents/puerto_rico_landfills_fact_sheet_final_0.pdf
- Arecibo W2E proposal is for 67MW, https://www.rd.usda.gov/files/UWP_ScopingReport_English.pdf
- SJ could produce 2-4 million gallons of diesel annually, http://senado.pr.gov/SiteCollectionDocuments/energia/7%20Presentacion_Energia_Renovable_PR_ARET_Dr._Colucci.pdf
- Landfills and other brownfields can host solar, see e.g. https://archive.epa.gov/region02/PR_Landfills_Solar/web/pdf/52181.pdf

Puerto Rico Landfill Consent Orders and Consent Decree - Closure Status

Landfill	Closure Status	Recycling & Composting Program Required	New Cell Construction
Aguadilla	Closed April 2010	No	No
Arecibo (Consent Decree)	After reaching final capacity (circa 2020)	Yes	No
Arroyo	Permanent waste receipt cessation required June 2019	Yes	No
Cayey	Permanent waste receipt cessation required January 2018	Yes	Under consideration
Florida	Overdue - permanent waste receipt cessation required June 2016	Yes	No
Isabela	June 2020 (only limited waste now being received)	Yes	Planned
Juncos	Permanent waste receipt cessation required December 2014 – Extended	Yes	Under construction
Lajas	December 2017	Yes	Planned
Moca	After reaching final capacity (circa 2019)	Yes	Planned
Santa Isabel	Interim closure completed September 2014	Yes	No
Toa Baja	Permanent waste receipt cessation September 2014 (achieved September 2015) and closure thereafter per closure plan schedule (pending)	Yes	Operational
Vega Baja	Permanent waste receipt cessation July 2013 (achieved July 2015) and closure thereafter per closure plan schedule (pending)	Yes	Operational

PR Ocean Resource

- Near-shore depths provide thermal gradient necessary for useful work
- Recoverable wave potential 20TWh/year, EPRI https://energy.gov/sites/prod/files/2013/12/f5/mappingandassessment.pdf



Hydro

- ~100MW potential from existing sites in disrepair

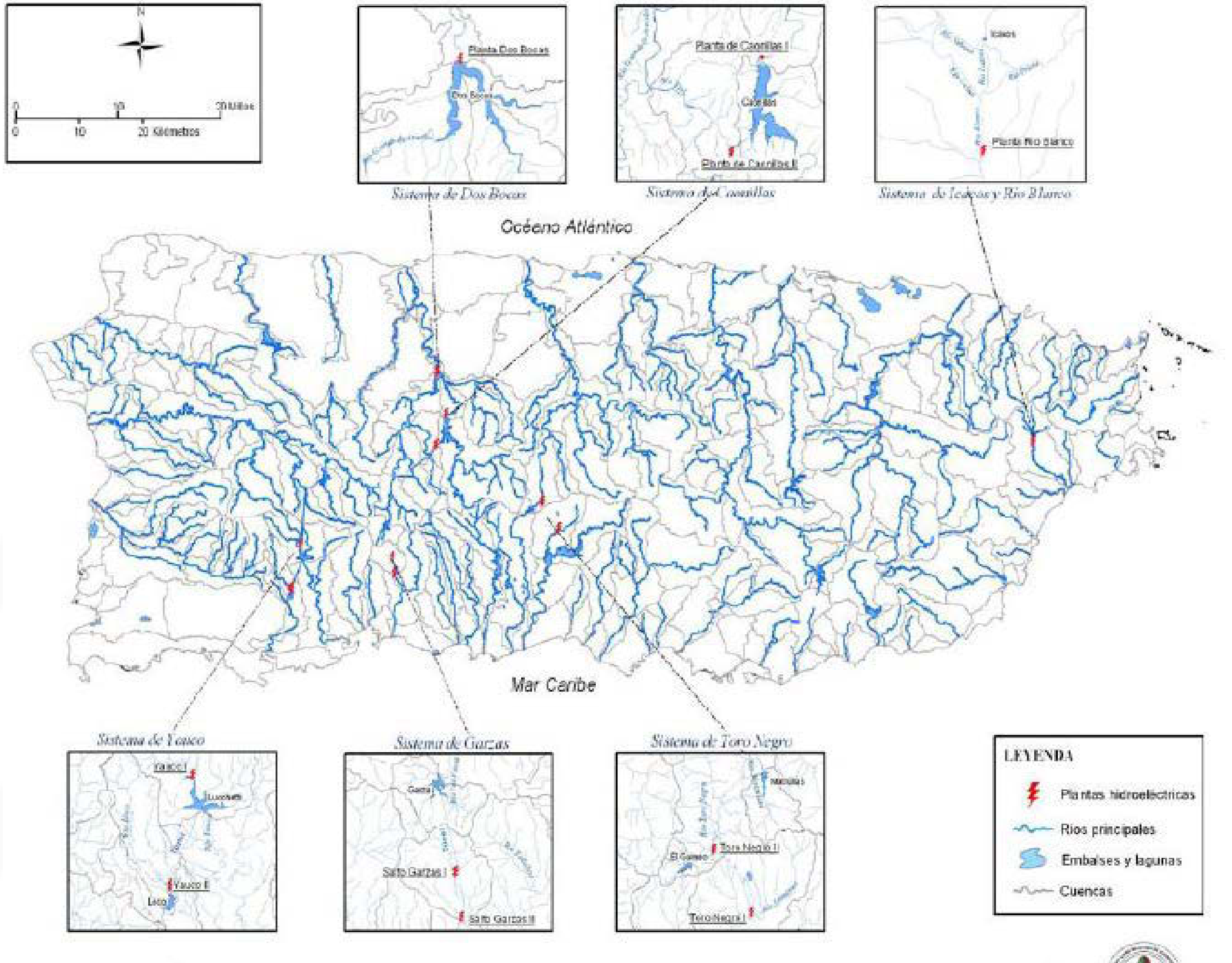


Figura 5.0-1 Localización de los sistemas hidroeléctricos activos en Puerto Rico

Phase 1&2 Analysis Working Vision
A Multi-Year Transition

Phase 2 shift toward validation of proposals for Federal investment

- Focus on immediate needs related to HUD CDBG-DR, while still addressing long-standing technical and institutional issues.
- Build confidence in funding decisions by agencies without mission in electricity system investment or operations.
- Identify assets and solutions serving HUD priority areas of low-moderate income areas

3 years

2018-2020

- ➢ Complete all final repairs; selected T&D upgrades
- ➢ Resolve financial uncertainties & ownership
- ➢ Develop initial microgrids
- ➢ Start institutional assessment & changes
- ➢ End enhanced lab technical assistance

5 years

2022

- ➢ Complete all T&D upgrades
- ➢ Complete initial phase of public-private partnerships (including microgrids)
- ➢ Complete institutional changes

5-10 years

2027

- ➢ Plan for sustainable improvements
- ➢ Stable regulatory structure and functioning market for advanced services

Phase 2 Lab Work Supporting Federal Funds

Issue	Lab	Phase 1 Deliverable Available for CDBG-DR Action Plan	Phase 2 Available to Validate CDBG-DR Proposals
Capacity expansion: focus on Palo Seco	ANL		Y
Fuels impacts: focus on LNG for PR & region	ANL		Y
Telecom impacts	ANL		Y
Transmission priorities	PNNL	Y	Y
T&D benefit-cost	PNNL		Y
Protection schemes, incl. real-time sensor info	ORNL	Y	Y
Renewables capacity expansion and integration	NREL	Y	Y
Bulk storage placement	SNL	Y	Y
Microgrid placement	SNL	Y	Y
DER and microgrid interconnection	SNL, NREL		Y
End-of-line communities resiliency	SNL, NREL		Y
Training for grantees and other stakeholders	NREL, SNL, PNNL		Y

Phase 2 Lab Work Coordination

Joint OE-EE active project management, with OE staff on day-to-day coordination (S. Walls and A. Breckel)

- Quarterly all-task calls, similar to GMI
- OE – Single lab weekly/bi-weekly calls
- Inter-office weekly/bi-weekly mtgs
- Coordination among capacity expansion, production cost, integration, and protection modelling and analytical efforts
- Coordination among other existing efforts, e.g., GIS resiliency tools at PNNL, SNL, ANL, NREL

Outputs delivered to:

- Flexible, quick response allocations at each performer lab to be leveraged as analytical insights needed by HUD, FEMA, other fed. partners (e.g., OMB)
- Info sharing with Puerto Rico Gov't (COR3, PREC/Energy Bureau, PREPA, etc.)
- Training and open source tools focused on university, industry groups, municipalities, others.
- Training opportunities made available to USVI, given HUD/FEMA role there

Phase 2 Topics

Fuels/Interdependencies
- LNG Infrastructure
- Telecom Infrastructure
- Solar Resource and Supply Curves

Bulk Power System
- Investment Support Tools
- Capacity Expansion Modeling (AURORA)
- Production Cost Modeling (FESTIV)
- System Stability Modeling (Epfast)
- Dynamic Modeling (MAFRIT)

Transmission
- Protection and R/T Info
- Risk-Based Contingency Analysis
- Grid Asset Benefit-Cost Evaluations

Distribution & Edge
- System Advisory Model & PVWatts
- DER Interconnection Standards
- DER Feeder Hosting Methodology
- Contingencies, Operations, and Storage Sizing for Islandable Sections
- GIS Resiliency Improvement Tool

Lead Lab Key:
- ANL
- NREL
- ORNL
- PNNL
- SNL

U.S. DEPARTMENT OF ENERGY
Office of Electricity

30 Technical Recommendations by Subject Matter Area

Recommendations by Subject Matter

Transmission and Distribution -1

1. Investments in grid improvements should be based on detailed modeling, such as load flow modeling and contingency analysis, to identify the optimal resiliency and hardening benefits for the transmission system. Re-routing transmission infrastructure does not now, in the absence of analysis demonstrating its merit, present sufficient benefit to justify the cost. Load flow and contingency analysis will reveal which lines should be re-routed to increase both day-to-day reliability and resilience in the case of an event. This modeling will help right-size and prioritize grid investments, which could otherwise have the potential to put significant upward pressure on rates.
2. Recovery plans should provide for enhanced and enforced operations and maintenance to mitigate the disruption caused by the next event. For example, guy wire anchors of transmission infrastructure and static wire continuity need to be maintained to harden and add resiliency. Other materials, such as stainless steel or composite anchors, may be needed to replace some components at existing installations.
3. There are no recommended modifications to the current voltages associated with the Transmission and Distribution (T&D) infrastructure as they are suitable for the current and projected electrical needs of the island. However, a long term strategy to maintain standardization with typical mainland voltage will help future mutual aid response.
4. USDA Rural Utilities Service (RUS) standards should be adopted where feasible and appropriate to standardize equipment and design, which will aid with replacement in both regular and emergency situations. USDA RUS standards govern the engineering and component specification of all voltage ranges of electrical transmission and distribution networks used by every rural electric utility in North America that borrows from RUS. PREPA was an active RUS borrower until 2010, so restoring the power grid to meet applicable RUS standards should be an attainable objective to prepare the utility for near term emergencies and long term investments. Thus, as part of the reconstruction phase, Puerto Rico's grid should be restored, at a minimum, to RUS standards as well as other applicable standards (e.g., NESC, NEC, NERC-CIP, NIST cybersecurity framework).
5. All replaced poles and towers should be of a design and material to survive 150 mph sustained winds. If funds are available, electricity transmission towers installed specifically for temporary emergency restoration after Hurricanes Irma and Maria should be considered for replacement as soon as practicable, potentially by monopoles. Many round monopole structures rode through the storm effectively.
6. The PREC should coordinate a joint study with the Puerto Rico Telecommunications Board to determine and enforce safe loading requirements of distribution poles carrying both electric and telecommunications infrastructure. Federal agencies can participate as necessary and appropriate.

Recommendations by Subject Matter

Transmission and Distribution -2

7. Implement industry best practices in a comprehensive vegetation management program to protect the integrity of grid assets.
8. Substation assets should be hardened, including transformers, circuit breakers, associated switchgear, and especially control equipment, including protective relays and communications gear. Revised Flood Insurance Rate Maps (FIRM) should be used to site substation assets to avoid Base Flood Elevation (BFE) + 3.0 feet or 0.2% flood elevation, whichever is higher. In addition, siting should be outside of the floodplain whenever possible and existing critical stations should be raised and/or waterproofed accordingly. Besides relocation, detailed power system simulation will provide insights on which assets to harden and in what priority.
9. Based on modeling results, strategic, judicious undergrounding of distribution lines should be considered in limited appropriate circumstances. Based on experiences in Hurricanes Katrina and Sandy, undergrounding of lines in coastal areas could present risk of salt-water intrusion; other considerations are the depth of the island’s water table and subsurface rock. Any underground distribution lines in a floodplain should conform to 10 CFR Part 1022.
10. For the benefit of both day-to-day and in-event scenarios, recovery plans should include a strong modern Energy Management System, Remote Terminal Units, and other equipment providing real-time information and control capability to utility operators. For example, AMI for metering to serve as an operational tool providing real-time information that can, if implemented appropriately, improve service to industrial customers and reduce non-technical losses (caused by actions external to the power system such as theft) by enabling targeted inspections of anomalous readings. Also, this intelligence could empower a predictive maintenance program.
11. Analysis of the existing communication infrastructure available to support grid monitoring and control functionality should be performed. This analysis would include: inventory and document the existing fiber optic cable plant; research ownership of existing cables; determine fiber connections and fiber terminations availability for secure utility applications; analyze availability and functional performance and cybersecurity of the existing communication termination equipment at the substations; identify suitable solutions to support "last mile" communications to enable system monitoring and control functions, sensors and other equipment; distribution automation, support; AMI data backhaul; and other applications and functions.
12. Analysis should be conducted to determine the value of deliberate sectionalizing of the grid.

Recommendations by Subject Matter

Generation

13. Evaluate the siting of key generation facilities so that, to the extent practicable, they are co-located with key load centers to reduce the criticality of the transmission system when recovering from anticipated extreme events in the future. In particular, analysis on re-powering Palo Seco with alternative fossil fuels is recommended.
14. Ensure the generation mix complies with all relevant legal and regulatory requirements, both local and Federal. Preliminary analysis shows that moving toward a more diverse fuel portfolio, including alternative fossil fuels, renewable energy and energy efficiency, will produce significant cost reductions. Fuel-efficient load-following combustion turbines could greatly improve fuel efficiency as compared to conventional steam turbine power plants. However, as with grid infrastructure, detailed modeling, such as production cost, capacity expansion analysis and detailed machine modeling, can help determine the best course of action to integrating new generation sources for Puerto Rico.
15. Given PREPA's pre-storm estimated sales in 2026, as few as three of PREPA's current power plants may satisfy estimated load in ten years, when combined with purchased power. Any hardening efforts should focus on those plants, including the Costa Sur power plant. As other facilities are retrofitted, especially Palo Seco, to comply with Mercury and Air Toxic Standards (MATS) and other relevant legal requirements, detailed hardening assessments should be undertaken.
16. Evaluate the extent to which integrating small and flexible generation assets near load centers into a more intelligent system could reduce the number of critical failure points.
17. While much of PREPA's generation that was operational before the storm was not significantly compromised by Hurricanes Irma or Maria, a program of hardening generation assets would ensure continued resilience to weather events, beginning with critical central plants regardless of ownership. The current excess of generation affords the opportunity to model energy interdependencies and assess fuel contingencies, including shipping concerns, source of fuels, storage locations, and the impact of disruption and emergency response. Analysis can indicate where to prioritize dual fuel generation capability and sufficient levels of on-site fuel storage.

Recommendations by Subject Matter
Microgrids

18. Recovery plans should include analysis to determine the potential applicability and optimal locations for microgrids, including their specialized role in the system (e.g., serving critical infrastructure in urban areas, serving unique needs of industrial customers, or serving remote communities). This analysis should include the availability of generation resources, fuels, load type, and the boundaries of microgrids.
19. Microgrid designs should rely on a suite of existing tools (e.g., DER-CAM, and the Microgrid Design Tool – see Appendix D) to help design and value microgrids, once their location(s) has been identified.
20. Communities that have required generator assets for extended periods of time should consider microgrids and the potential to leverage temporary generation that has been in service over the past few months.
21. Analysis as part of the recovery plan should consider and evaluate different pathways to contain grid failures during future events, and the different roles of transmission sectionalization and microgrids in providing reliability and resilience.
22. Interdependencies between electric power and other key sectors, specifically water, waste water, waste, telecommunications, transportation, and public health and safety, should be assessed and considered when infrastructure funding decisions are made. Potential alignment and sequencing of federal funding across different agency programs that support various sector infrastructures, possibly across multiple areas of the islands would be beneficial. The analysis identified in this report will support that goal.
23. Microgrids may prove effective at ensuring the availability of critical services during an event. Analysis can help prioritize critical infrastructure for hardening, for example, through a critical infrastructure resiliency bank.

On-Going System Operations, Management, and Planning

24. Training and capacity building, particularly on asset management, system planning, and data collection should be supported as a part of all infrastructure expenditures, including Integrated Resource Planning, Energy Assurance Planning, and cost of service accounting.
25. PREPA, PREC, and other Commonwealth agencies and instrumentalities should be resourced to draft and execute staff training plans as part of expenditures on infrastructure. To the extent necessary, PREPA should identify skills gaps within its technical and engineering staffs, and identify whether other groups (such as Administrative and General) are right-sized to forecasted sales and engineering needs.
26. The recovery plan should call on the utility to identify a core team responsible for IRP submissions and other regulatory affairs, set aside sufficient resources for their work and data collection, and utilize additional training from relevant national organizations.
27. The Puerto Rican State Office of Energy Policy or its successor should immediately draft an updated Energy Assurance Plan, which should be reviewed on an annual basis.
28. Ensure that any and all funded projects are consistent with approved and vetted long-term plans that provide reasonable assurances of compliance with all local and federal laws and regulations.
29. The Governor and PREPA should update mutual aid agreements to facilitate the rapid sharing of emergency aid and resources and ensure that Incident Command Systems are primed to quickly provide support during the next event.
30. Consider additional legislation and regulation that may improve reliability and resiliency including, without limitation: regulations that prescribe design and installation standards for all T&D towers and poles to withstand 150 mph wind speed, regardless of material; all critical electricity system assets should be located at BFE + 3 feet or the 0.2% flood elevation, whichever is higher, or sited outside the flood plain entirely, if possible (see note in Section C1 of this report); and an annual review of the Energy Assurance Plan, and all associated components, including mutual assistance agreements, and technical and logistical procedures for Incident Management Teams. To the extent feasible in order to enhance operational efficiencies and interoperability, regulatory agencies should consider and adopt relevant NERC reliability standards to be implemented by the Commonwealth.

Panel Discussion

- **Topic**
  Identifying priority needs for improving the capacity of Puerto Ricans to engage in energy transition efforts

- **Panelists**
  - Gabriel Perez, Regional Manager Caribbean Region, Blue Planet Energy Systems (and ACONER board member)
  - Ingrid M. Vila Biaggi, President/Co-founder, Cambio
  - Lillian Mateo Santos, Associate Commissioner, Puerto Rico Energy Bureau
  - Thomas R. McOsker, CEO, BCMG

Panel Discussion

- **Topic**
  Identifying priority needs for improving the capacity of Puerto Ricans to engage in energy transition efforts

- **Panelists**
  - Ernesto Rivera Suárez, President, Renewable Solutions Engineering (and former president of ACONER)
  - Ruth Santiago, Lawyer
  - Thomas King, Founding Director, Fundación Borincana

NREL Tools You Can Use

Nate Blair

National Renewable Energy Laboratory (NREL) at a Glance

1,700

Employees,
plus more than
400
early-career researchers and visiting scientists

World-class
facilities, renowned technology experts

nearly 750

Partnerships
with industry, academia, and government

Campus
operates as a living laboratory

$872M annually

National economic impact

NREL's Science Drives Innovation

Renewable Power

Solar

Wind

Water

Geothermal

Sustainable Transportation

Bioenergy

Vehicle Technologies

Hydrogen

Energy Efficiency

Buildings

Advanced Manufacturing

Government Energy Management

Energy Systems Integration

High-Performance Computing

Data and Visualizations

Tool Selection Criteria and Features

Selection Criteria:

- NREL-developed tools
- Free, publicly available, user-driven tools
- Goal is open-source; some accessible via API

Features:

- Inputs for tools that contain financial analysis are or can be modified to reflect low- and middle-income (LMI) customers

NREL Tools – user-driven and publicly available

Tool name	Data or tool ⇩	Users	Question it answers	Training available	Open source
National Solar Radiation Database (NSRDB)	Both	✓ Developers, engineers, or planners ✓ Researchers	What is the level of solar irradiance at my site?	User manuals, support forum, and data download steps online	Yes
State and Local Energy Data (SLED)	Data	✓ Developers, engineers, or planners ✓ State or local policymakers	What is the sector level breakdown of energy and emission data for my jurisdiction (or sub-jurisdictions)?	Easy-to-use data portal	n/a
BEopt	Tool	✓ Developers, engineers, or planners ✓ Home, business, or building owners ✓ Researchers	What are cost-optimal efficiency packages for various levels of whole-house energy savings for my building design?	Training videos and publications in support menu on website	No
Community Solar Scenario Tool (CSST)	Tool	✓ Developers, engineers, or planners ✓ Utilities and regulators ✓ State or local policymakers	What are the costs and benefits to various audiences of a single community solar project?	Tool documentation is included as cell comments	No
Jobs and Economic Development Impact (JEDI) models	Tool	✓ Developers, engineers, or planners ✓ Utilities and regulators ✓ State or local policymakers ✓ Home, building, or business owners	What are job and other economic development impacts of renewable energy projects in my jurisdiction?	Instructions online and in 'About Jedi' tab in the spreadsheet tool	Yes
PVWatts	Tool	✓ Developers, engineers, or planners ✓ Home, business, or building owners	What is the possible performance and annual value of my solar project?	Help button on website provides documentation	Yes
REopt Lite (full REopt on next slide)	Tool	✓ Developers, engineers, or planners ✓ State or local policymakers ✓ Home, business, or building owners ✓ Researchers	What combination of solar PV, wind, and energy storage will help my site minimize energy costs or sustain a grid outage? (For PR, supports solar plus storage only for now, not wind)	User manual and demo video online	In process
ResStock	Tool	✓ Developers, engineers, or planners ✓ Utilities and regulators ✓ State or local policymakers ✓ Home, business, or building owners	What energy efficiency measures are likely to yield the highest savings in my jurisdiction?	Documentation, publications and a webinar available online	Yes
System Advisor Model (SAM)	Tool	✓ Developers, engineers, or planners ✓ State or local policymakers ✓ Researchers	What are the costs, cash flow, and performance predictions for my solar, wind, or geothermal project?	Quick start guide and extensive help menu within software; webinars online	Yes

National Solar Radiation Database (NSRDB)

A collection of meteorological and solar irradiance data sets for the U.S. and a growing list of international locations. The data are publicly available at no cost to the user, and can be downloaded or viewed using the Data Viewer.

Question it answers

What is the level of solar irradiance at my site?

How can I choose optimal locations for solar installations?

Relevance to PR

Data available for PR; developers are currently updating with increased resolution. Can help energy planners choose optimal locations for solar installations

Target users

- ✓ Developers, engineers, or planners
- ✓ Researchers

Training available

User manuals, support forum, and data download steps online

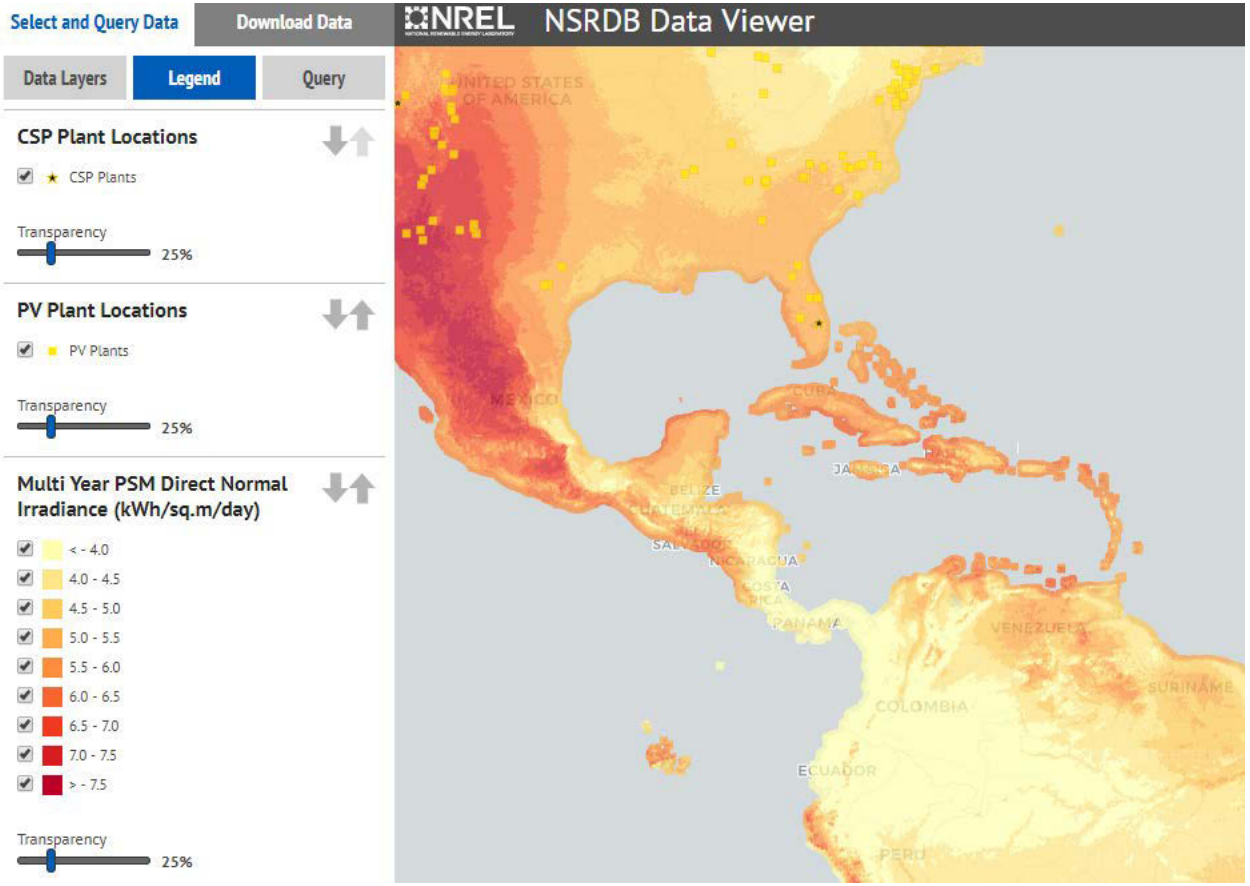
Open source

Yes

Link

https://nsrdb.nrel.gov/

https://maps.nrel.gov/nsrdb-viewer



State and Local Energy Data (SLED)

Energy Profiles provide comprehensive energy use and activity data to help cities plan and implement clean energy projects, and include summary reports on: greenhouse gas emissions, electricity generation, natural gas and other fuel source costs, renewable energy resource potential, transportation, buildings, and industry data. The Toolbox is full of resources to help cities take action.

Question it answers

What is the sector level breakdown of energy and emission data for my jurisdiction (or sub-jurisdictions)?

Relevance to PR

Does not have PR data but could be used as comparator in like microclimates and demographics

Target users

- ✓ Developers, engineers, or planners
- ✓ State or local policymakers
- ✓ Researchers

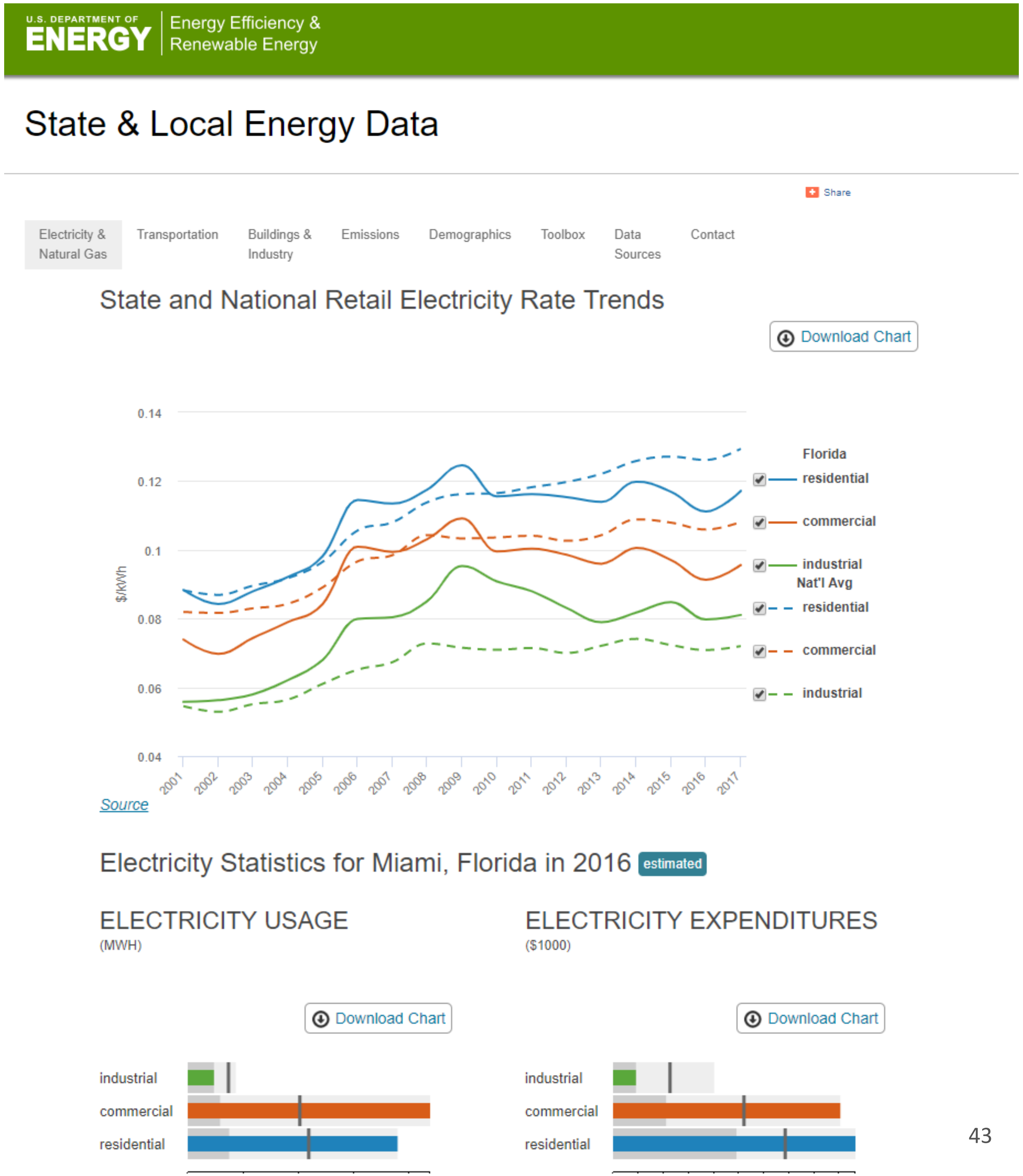
Training available

Documentation, publications and a webinar available online

Open source: n/a

Link

https://apps1.eere.energy.gov/sled/#/



Building Energy Optimization Tool (BEopt)

Evaluate residential building designs and identify cost-optimal efficiency packages at various levels of whole-house energy savings along the path to zero net energy. Provides detailed simulation-based analysis based on specific house characteristics, such as size, architecture, occupancy, location, and utility rates. Discrete envelope and equipment options reflecting construction materials and practices are evaluated.

Question it answers

What are cost-optimal energy efficiency packages for various levels of whole-house energy savings for my building design?

Target users

- ✓ Developers, engineers, or planners
- ✓ Home, business, or building owners
- ✓ Researchers

Open source: No

Relevance to PR

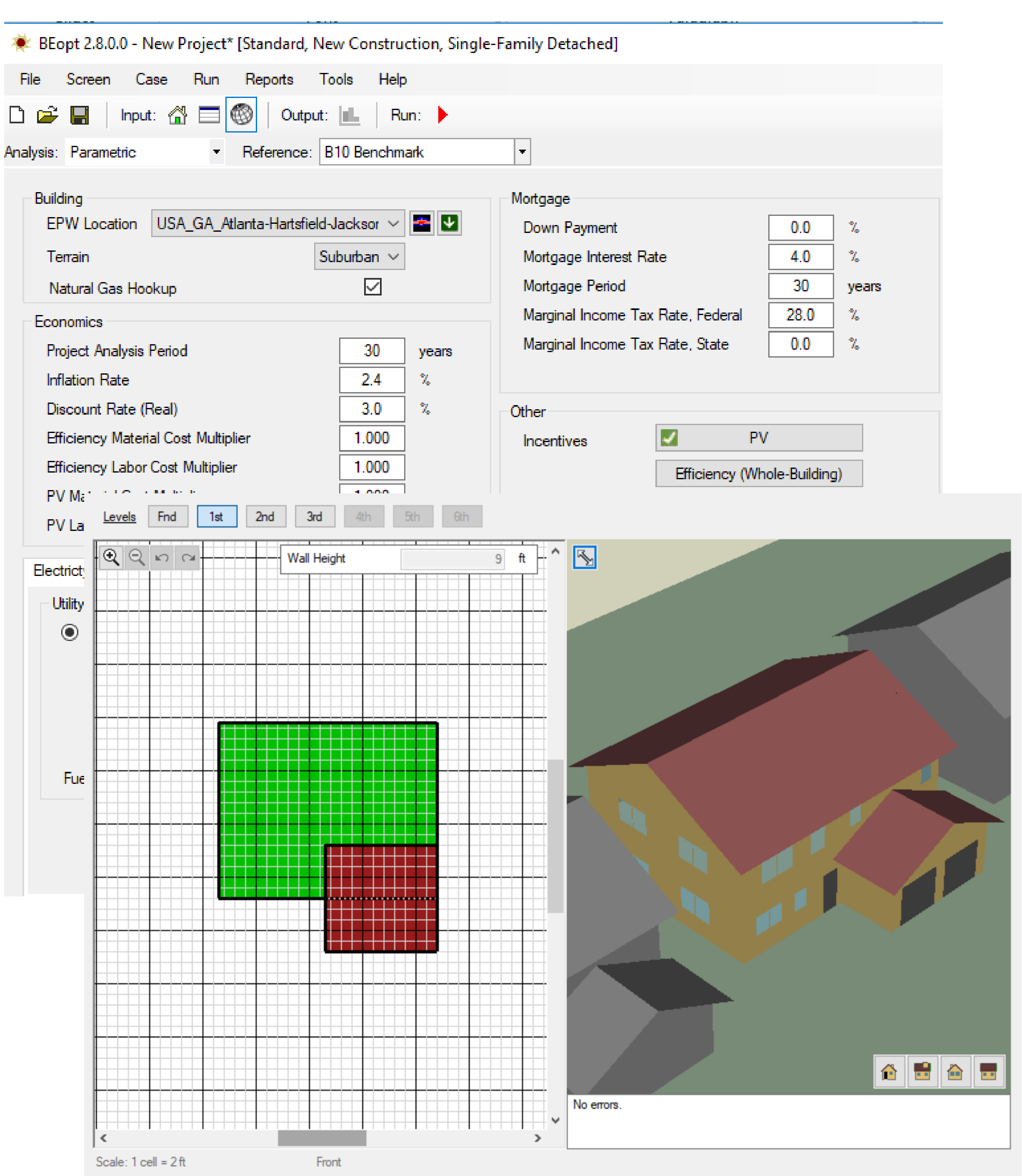
In optimization mode PR users could manually enter cost data rather than using default national averages. Could also be used for investigating energy savings of different efficiency measures

Training available

Training videos and publications in support menu on website

Link

https://beopt.nrel.gov/



Community Solar Scenario Tool (CSST)

Provides a "first cut" analysis of different community or shared solar program options. Allows users to see how various inputs impact the economics of a project from both a potential customer's perspective as well as that of the sponsoring utility.

Question it answers

What are the costs and benefits to various audiences of a single community solar project?

Relevance to PR

PR data available. Could help communities evaluate applicability of community solar projects.

Target users

- ✓ Developers, engineers, or planners
- ✓ Utilities and regulators
- ✓ State or local policymakers

Training available

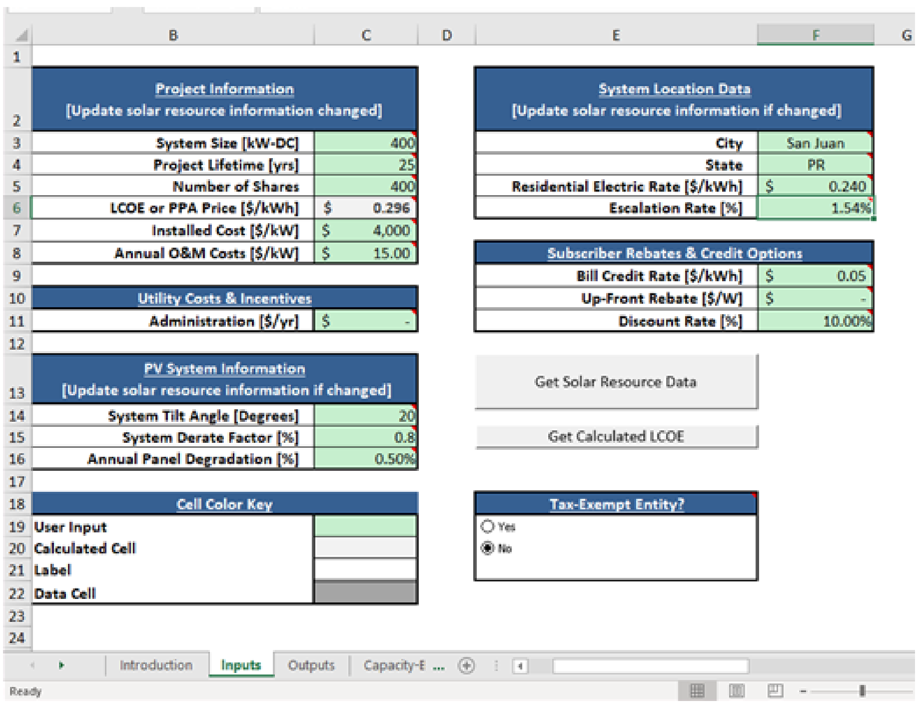
Tool documentation is included as cell comments

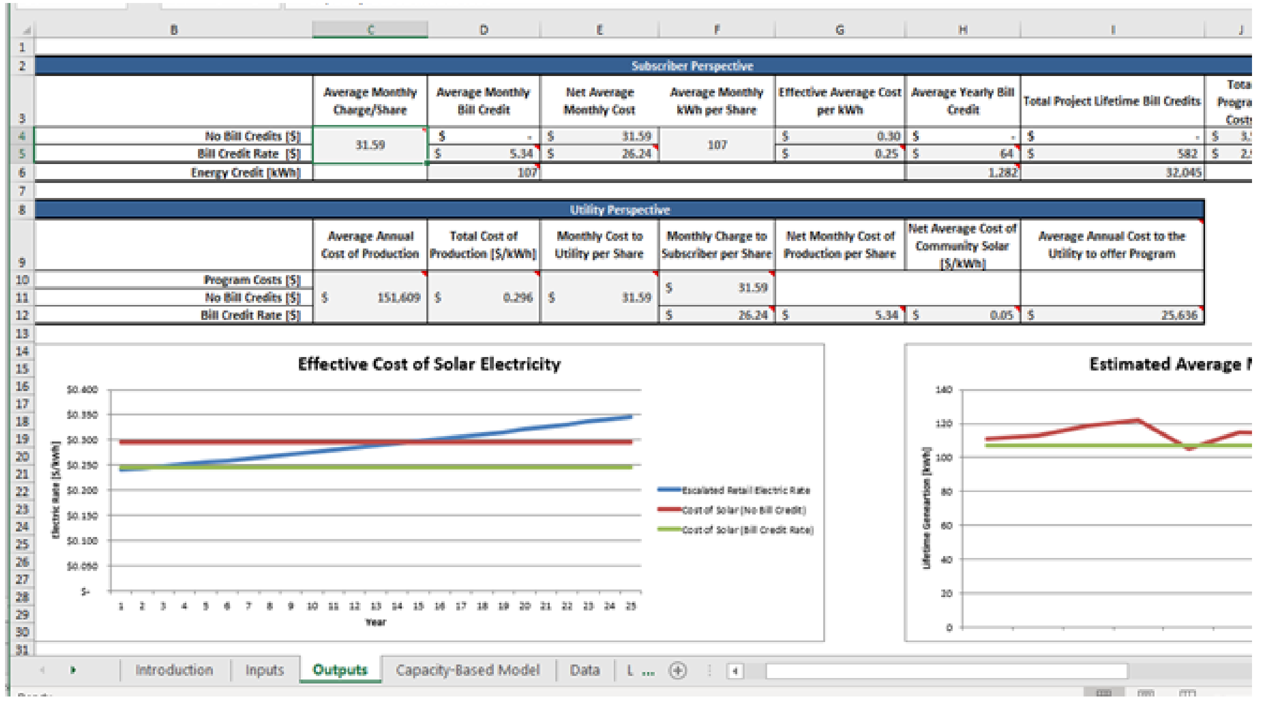
Open source

No

Link

https://www.nrel.gov/energy-solutions/csst.html





Jobs and Economic Development Impact (JEDI) models

User-friendly tools that estimate economic impacts of constructing and operating power generation and biofuel plants at local and state levels. Based on user-entered project-specific data or default inputs (derived from industry norms), JEDI estimates the number of jobs and economic impacts to a local area that can reasonably be supported by a power plant, fuel production facility, or other project.

Question it answers

What are job and other economic development impacts of non-solar renewable energy projects in my jurisdiction?

Relevance to PR

Does not have PR data but could be used as comparator in like microclimates and demographics

Target users

- ✓ Developers, engineers, or planners
- ✓ Home, building, or business owners
- ✓ Utilities and regulators
- ✓ State or local policymakers

Training available

Instructions online and in 'About Jedi' tab in the spreadsheet tool

Open source: Yes

Link

https://www.nrel.gov/analysis/jedi/about.html

	A	B	C	D	E
13	**Project Descriptive Data**				
14	Project Location	FLORIDA			
15					
16	Solar Direct Normal Resource (kWh/m2/day)	7.65			
17	Year of Construction	2011			
18	Project Size - Nameplate Capacity (MW)	100			
19	Solar Field Aperture Area (square meters)	776,364			
20	Plant Capacity Factor	41.7%			
21	Construction Cost ($/KW)	$6,270			
22	Annual Operations and Maintenance Cost ($/kW)	$78.15			
23	Money Value - Current or Constant (Dollar Year)	2009			
24					
25–27	Utilize *Project Cost Data* default values? Choose "Y" to accept default values below or "N" to over-ride default values and utilize new user defined values as entered below.	Y	Press 'Go To Summary Impacts' Button Go To Summary Impacts		
28	If desired, default values (in cells below - based on *Project Descriptive Data* entered above) may be restored by pressing the 'Restore Default Values' button. *Note: it is not necessary to restore defaults to incorporate default Project Cost Data in system analysis (simply enter a "Y" in cell B25 above).*				
29					
30	**Project Cost Data - Default Values**				
31	Construction Costs	Cost	Cost	Percent of	
32	Materials		Per KW	Total Cost	Local Share
33	Construction (concrete rebar, equip, roads and site prep)	$16,731,933	$167	2.6%	95%
34	Materials Subtotal	$16,731,933	$167	2.6%	
35	Labor				
36	Sitework and Infrastructure	$4,720,551	$47	0.7%	100%
37	Field Erection	$56,424,736	$564	8.6%	100%
38	Support Structures	$3,333,604	$33	0.5%	100%
39	Piping	$18,408,323	$184	2.8%	100%
40	Electrical	$7,344,702	$73	1.1%	100%
41	Labor Subtotal	$90,231,916	$902	13.79%	
42	Construction Subtotal	$106,963,849	$1,070	16.3%	
43	Equipment Costs				
44	Mirrors	$37,102,435	$371	5.7%	0%
45	Heat Collection Elements	$117,638,503	$1,176	18.0%	0%
46	Thermal Energy Storage Tanks	$34,159,623	$342	5.2%	42%
47	Heat Exchangers	$25,377,755	$254	3.9%	0%
48	Heat Transfer System Equipment	$20,818,817	$208	3.2%	34%
49	Heat Transfer and Storage Fluids	$73,478,069	$735	11.2%	10%
50	Steam Turbines & Generators	$49,652,526	$497	7.6%	12%
51	Misc. Electrical and Solar Equipment (pumps, motors, drive,	$1,671,824	$17	0.3%	59%
52	Water Treatment	$1,446,296	$14	0.2%	50%
53	Metal Support Structure	$22,276,983	$223	3.4%	50%
54	Interconnection Piping	$32,367,275	$324	4.9%	59%
55	Electronics & Controls	$11,189,623	$112	1.7%	50%
56	Balance of Plant	$12,766,488	$128	2.0%	50%
57	Equipment Subtotal	$439,946,217	$4,399	67.2%	

About JEDI | FAQ | Start

PVWatts*

A calculator that estimates the energy production and cost of energy of grid-connected photovoltaic (PV) energy systems throughout the world. Allows users to easily develop estimates of the performance of potential PV installations. Uses newest data from the NREL National Solar Radiation Database (NSRDB).

Question it answers

What is the possible performance and annual value of my solar project?

Relevance to PR

PR data is included and available at a 4km grid scale

Target users

✓ Developers, engineers, or planners
✓ Home, business, or building owners

Training available

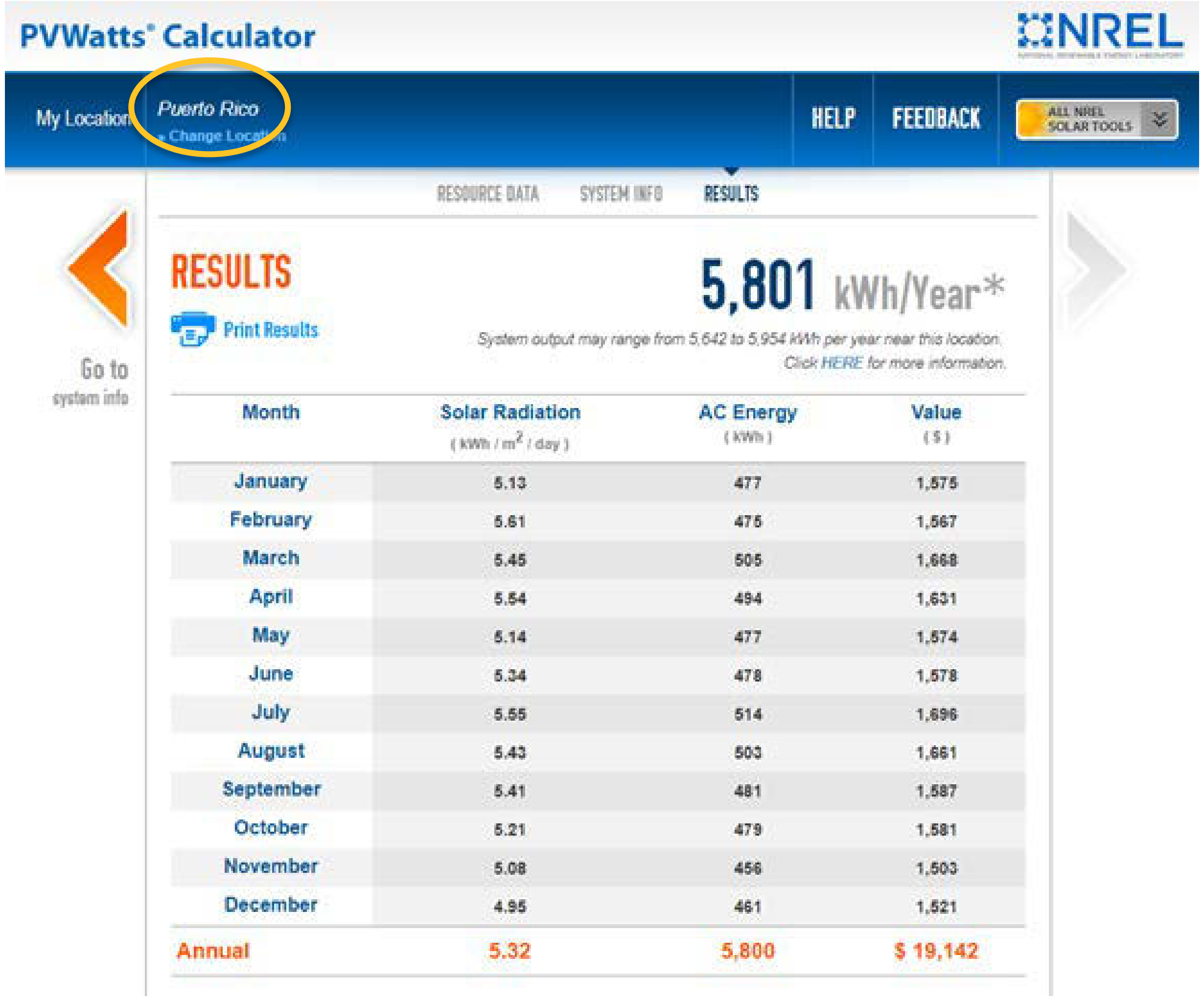
Help button on website provides documentation

Open source

Yes

Link

https://pvwatts.nrel.gov/



Month	Solar Radiation (kWh / m² / day)	AC Energy (kWh)	Value ($)
January	5.13	477	1,575
February	5.61	475	1,567
March	5.45	505	1,668
April	5.54	494	1,631
May	5.14	477	1,574
June	5.34	478	1,578
July	5.55	514	1,696
August	5.43	503	1,661
September	5.41	481	1,587
October	5.21	479	1,581
November	5.08	456	1,503
December	4.95	461	1,521
Annual	5.32	5,800	$ 19,142

*Also available in SAM with expanded capabilities

REopt Lite*

A decision support tool used to optimize energy systems for buildings, campuses, communities, and microgrids. Recommends an optimal mix of renewable energy, conventional generation, and energy storage technologies to meet cost savings and energy performance goals. REopt Lite is a subset of the full model's capabilities available at no cost to the user.

Question it answers

What combination of solar PV, wind, and energy storage will help my site minimize energy costs or sustain a grid outage?

Relevance to PR

Supports solar and storage in PR only, not wind at this time. Does not have drop-down for selecting rates for PR, but advanced users with data can use custom feature

Target users

- ✓ Developers, engineers, or planners
- ✓ State or local policymakers
- ✓ Home, business, or building owners
- ✓ Researchers

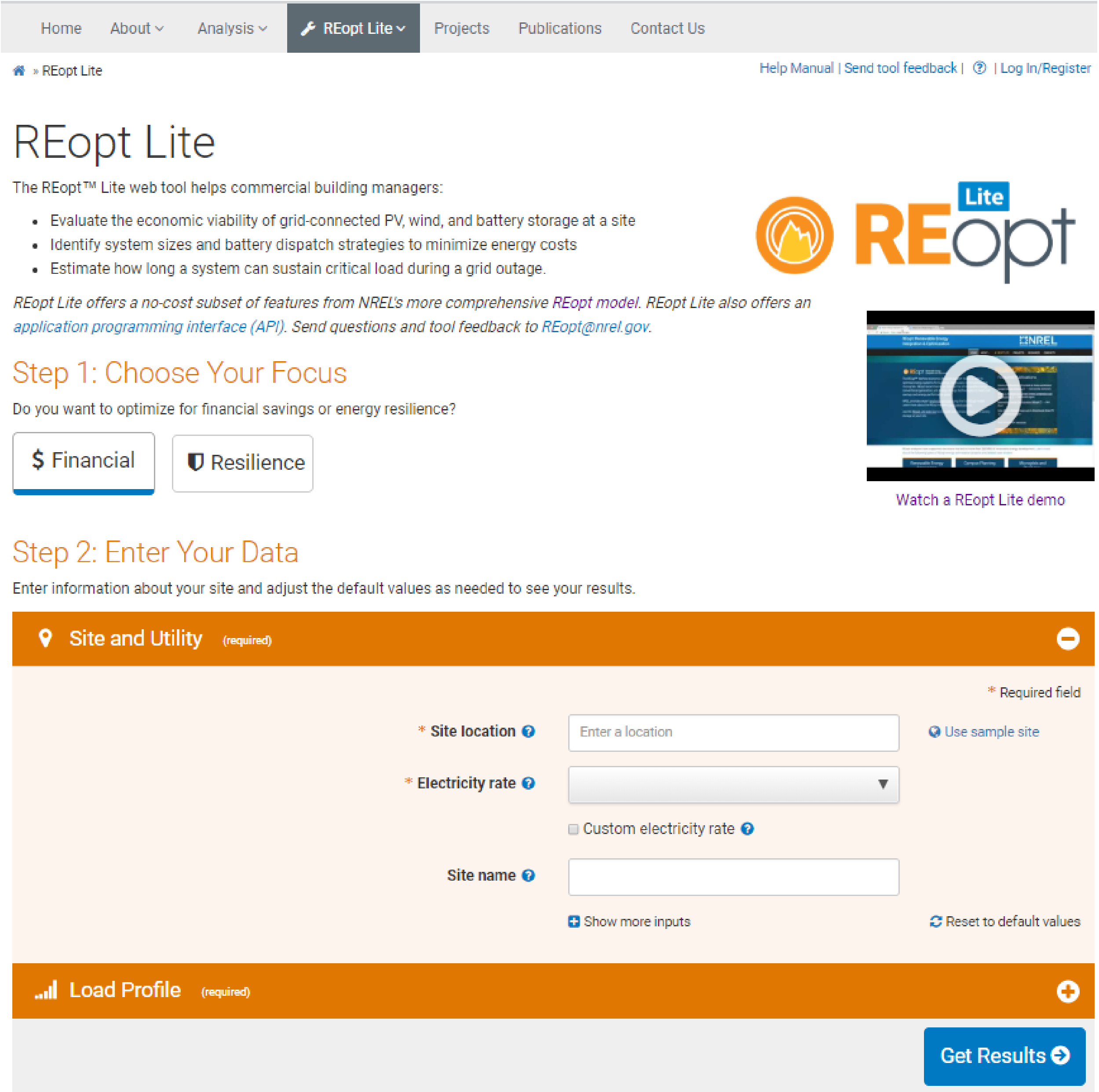
Training available

User manual and demo video online

Open source: In-progress; API

Link

https://reopt.nrel.gov/tool



*Additional REopt technologies and services available from NREL by agreement

ResStock

Performs large-scale residential energy analysis by combining public and private data sources, statistical sampling, detailed sub-hourly building simulations, and high-performance computing to help users identify which home improvements save the most energy and money.

Question it answers

- What energy efficiency measures yield the highest savings in my jurisdiction?
- How do opportunities vary by household income?

Relevance to PR

Does not have PR data but could use PR data from Census Bureau, along with other local data sources and local expert knowledge

Target users

✓ Utilities and regulators

✓ State or local policymakers

✓ Non-profits, academic researchers, and program implementers

Training available

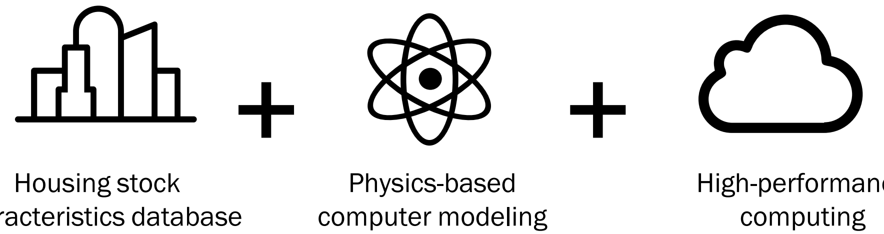
Documentation, publications, and webinar available online; customized trainings available

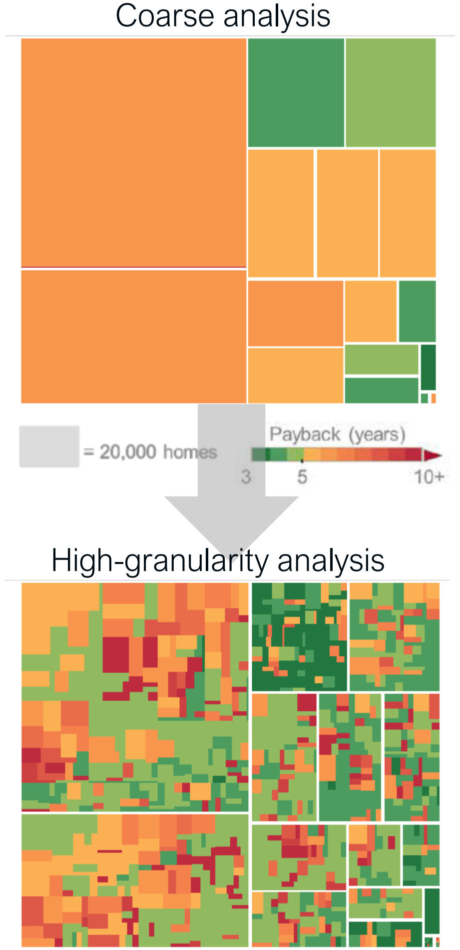
Open source: Yes

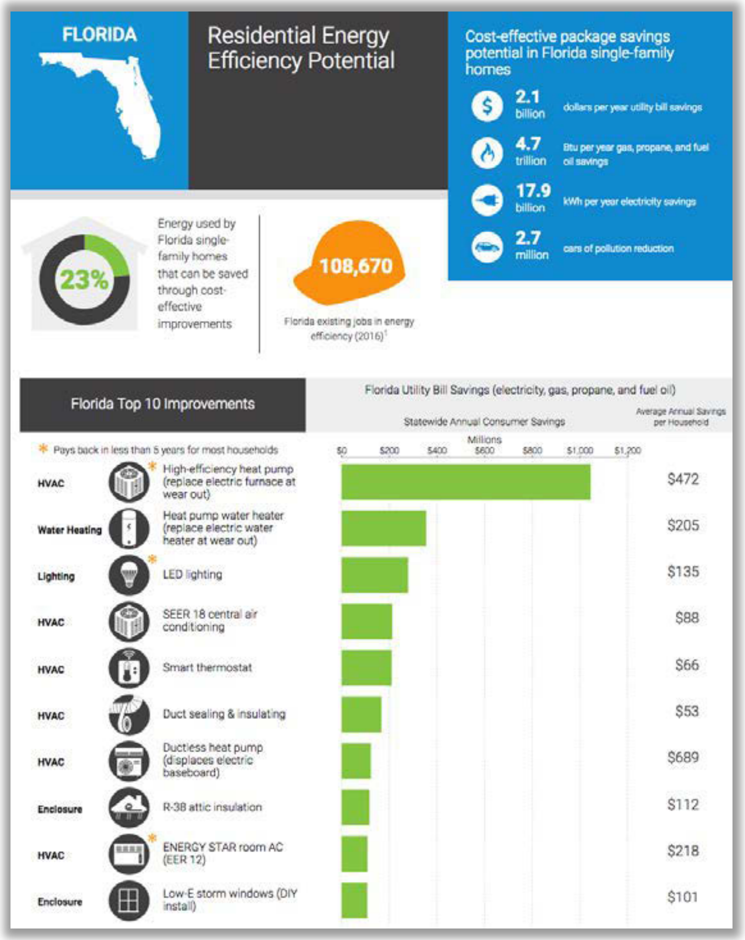
Link

https://resstock.nrel.gov/

ResStock







System Advisor Model (SAM)

A free computer program that calculates a renewable energy system's hourly energy output over a single year, and the cost of energy for a renewable energy project over the life of the project. These calculations are done using detailed performance models, a cash-flow finance model, and a library of reasonable default values for each technology and target market.

Question it answers

What are the costs, cash flow, and performance predictions for my solar (PV or CSP), wind, or geothermal project?

Target users

- ✓ Developers, engineers, or planners
- ✓ State or local policymakers
- ✓ Researchers

Open source

Yes; API available

Relevance to PR

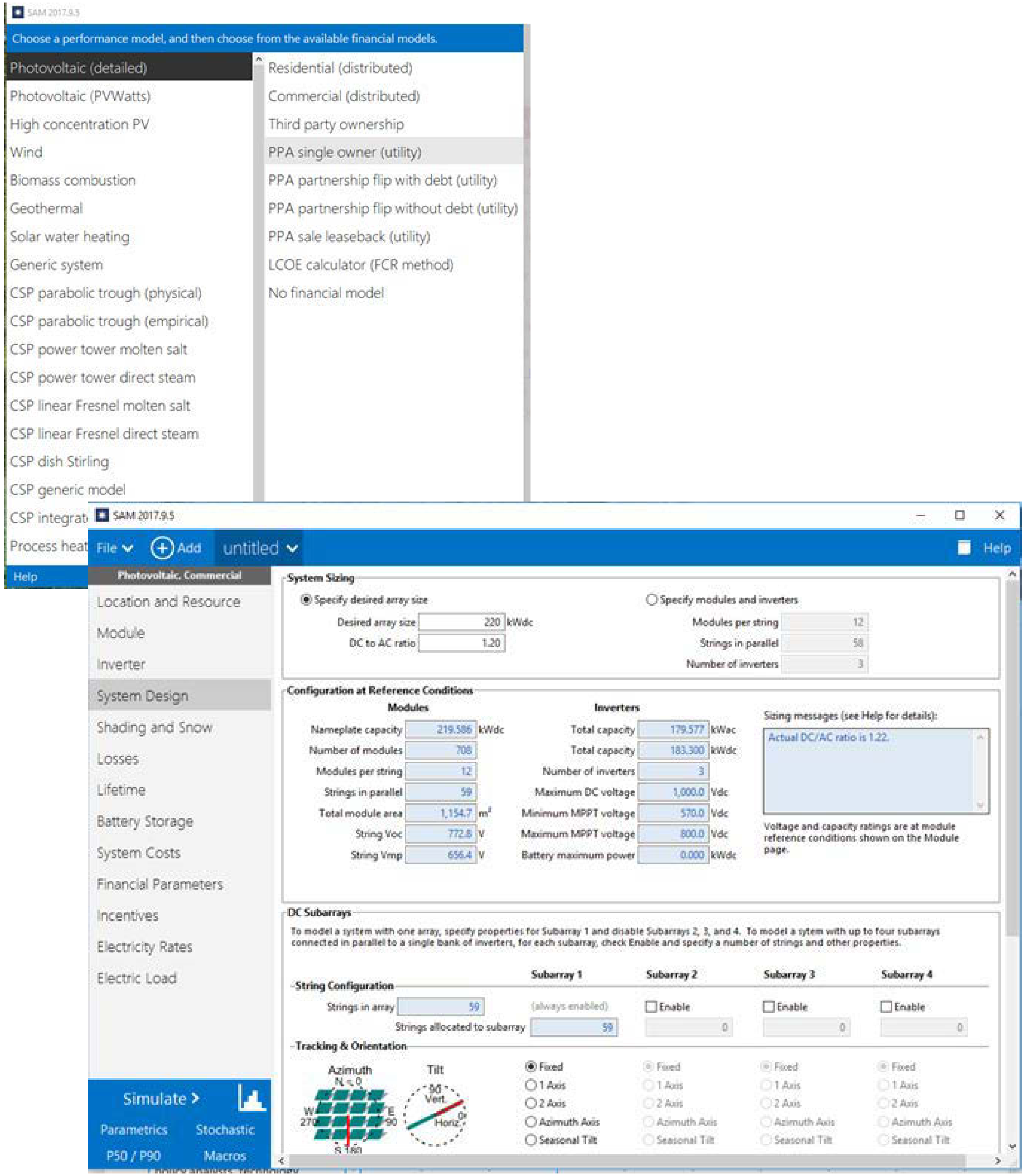
The tool can access solar data for Puerto Rico using the gridded solar data via the NSRDB

Training available

Quick start guide and extensive help menu within software; webinars online. Typically requires a larger investment in knowledge and time to use

Link

https://sam.nrel.gov/about



NREL Tools – used for in-house analysis

Tool name	Customers	Description	Link
Distributed Generation Market Demand (dGen) model	✓ State or local policymakers ✓ Utilities and regulators ✓ Researchers	A geospatially rich market-penetration model that simulates the potential adoption of distributed energy resources (DERs) for residential, commercial, and industrial entities in the United States through 2050. dGen is used primarily as an exploratory tool to determine how different factors will affect DER deployment	https://www.nrel.gov/analysis/dgen/
Flexible Energy Scheduling Tool for Integrating Variable Generation (FESTIV)	✓ Developers, engineers, or planners ✓ State or local policymakers	A multiple-timescale, interconnected simulation tool that includes security-constrained unit commitment, security-constrained economic dispatch, and automatic generation control sub-models. FESTIV simulates the behavior of the electric power system to help researchers understand the impacts of variability and uncertainty on power system operations	https://www.nrel.gov/grid/festiv-model.html
Multi-Area Frequency Response Integration Tool (MAFRIT)	✓ Developers, engineers, or planners ✓ Utilities and regulators ✓ Researchers	The only software tool of its kind that integrates primary frequency response (turbine governor control) with secondary frequency response (automatic generation control). MAFRIT simulates the power system dynamic response in full time spectrum with variable time steps from millisecond to days under both normal and event conditions. Places emphasis on electric power systems with high penetrations of renewable generation	https://www.nrel.gov/grid/modeling-tools.html
(ReEDS)	✓ State or local policymakers ✓ Utilities and regulators ✓ Researchers	Capacity planning and dispatch model for the North American Electricity system	https://www.nrel.gov/analysis/reeds/index.html
REopt	✓ Developers, engineers, or planners ✓ State or local policymakers ✓ Utilities and regulators ✓ Researchers	A decision support tool used to optimize energy systems for buildings, campuses, communities, and microgrids. Recommends an optimal mix of renewable energy, conventional generation, and energy storage technologies to meet cost savings and energy performance goals	https://reopt.nrel.gov/about/
Hawaii Energy Visualization Initiative (HEVI) tool	✓ State or local policymakers ✓ Utilities and regulators	A custom capacity and dispatch modeling system that can quickly provide insights on cross-sectoral questions. This tool is customized in partnership with the user (typically energy office or university) and NREL based on locally available data and information	https://www.energy.gov/eere/energy-modeling-tool

Argonne National Laboratory

Tools with Potential Application for Puerto Rico

Point of Contact:
Mark C. Petri
mcpetri@anl.gov

Tool name	Description	POC
Resilient Electricity Market Design, Operations, and Planning (ALEAF)	Power market design, operations, and planning tool.	Zhi Zhou
Estimating Physical Repair Times at Critical Infrastructure Facilities (RESTORE)	A stochastic model of the steps required to restore a system following an incident.	Jim Kavicky
Quick Turn-Around Cascading Power Outage Estimation (EPfast)	A deterministic model that explores the tendency of power systems to spiral into uncontrolled islanding triggered by either man-made or natural disturbances.	Edgar Portante
Bulk-Level Power and Distribution-Level System Restoration Planning and detailed Cascading Power Outage Estimation (EGRIP)	A simulation of cascading blackouts, considering dynamics, monitoring, protection, control, and re-dispatch.	Feng Qiu and Chen Chen
Petroleum Interdependency Tool (POLfast)	A steady-state compensated supply/ demand model that estimates potential regional supply shortfalls, determines mitigating measures, and estimates the potential increase in the price of petroleum and related impacts on the regional gross domestic product (GDP).	Steve Folga
Hurricane Customer Outage Forecasting (HEADOUT)	A spatial and relational model to predict outages electric customers due to tropical cyclones. The tool generates detailed results providing customer outage estimates and identifies assets at risk from storm surge; used in pre-landfall real-time analysis during hurricane season, for emergency preparedness exercises, and for system planning.	Leah Talaber
Emergency Management, Common Operating Picture, and Situational Awareness (onVCP/vBEOC)	The tools provide situational awareness and Common Operating Picture for drills/exercises and during actual events; SimCell allows to Run emergency preparedness exercises more efficiently.	Ed Tanzman
Integrated Water-Energy Systems Assessment Framework (IWESAF)	The tool links various models to evaluate impacts of water availability and riverine thermal regime on power plant operation, short-term power grid dispatch, and long-term planning.	Eugene Yan
Large-scale dynamics cascading simulation, analysis, and visualization (Dynamics Security Analysis Toolkit (DSAT))	A tool for transient security assessment, cascading failure dynamics simulation, steady-state security, optimal generation dispatch, transient-security constrained dispatch	Guenter Conzelmann
Liquefied Natural Gas Supply Disruption Analysis Tool (LNGfast)	This tool analyzes the LNG supply-demand chain in the Caribbean region, optimizes inter-terminal maritime transportation between a set of supply ports and a set of sparsely distributed receiving ports with given LNG demands	Steve Folga
Analysis of wired and wireless communication systems (TelcoFast)	Tool used to assess the redundancy and resilience of the wireline and wireless communications sectors, has been modified to predict hurricane impacts on the commercial communications sector in Puerto Rico	Steve Folga

Pacific Northwest National Laboratory (PNNL)

GridPIQ: Grid Project Impacts Quantification Web Calculator

Contact: Karen Studarus Karen.studarus@pnnl.gov

Screening tool for grid projects – various technologies (*e.g.* energy storage, PV) and impacts (*e.g.* inter-hour ramping, emissions, peak power)

Question it answers

"If Only I Could Quickly and Easily…"

- Ask many "what if?" questions about my system
- Screen grid project ideas
- Visualize grid time series
- Compare assumptions
- Sanity check results
- Check for knock-on benefits or unintended consequences
- Document benefits of my project or product
- Leverage many data sources in one place

Target users

- ✓ Developers, engineers, or planners
- ✓ Researchers
- ✓ State or local policymakers

Relevance to PR

Some data available for PR. Can help energy planners choose optimal locations for solar and storage installations.

Open source

Mainly, open and transparent methods

Training available

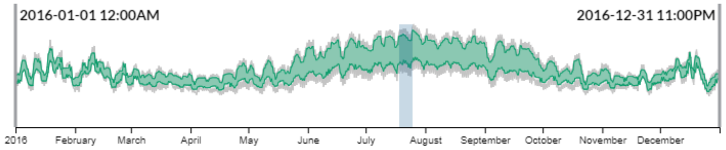
Instructions, and user tutorial example projects built into the online tool

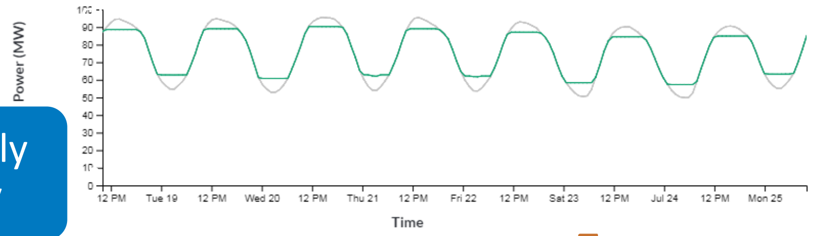
Link

gridpiq.pnnl.gov

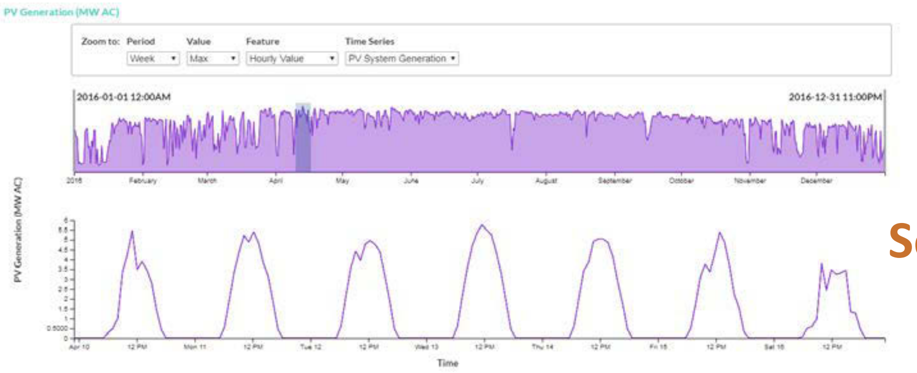
Pacific Northwest NATIONAL LABORATORY

Your Analysis → Hourly .csv → GridPIQ → Results





Energy Storage



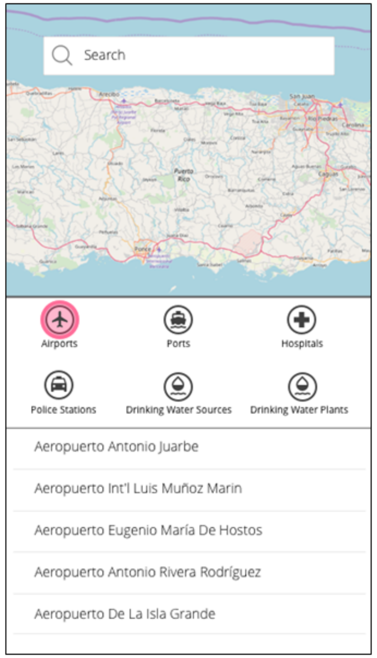
Solar PV

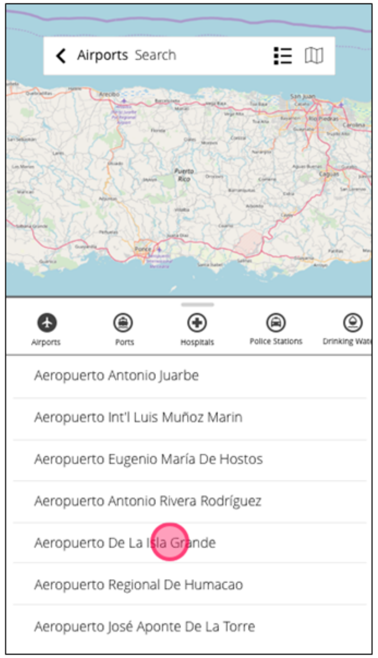
PV Modeling directly uses NREL's PV Watts, part of the System Advisor Model

Electrical Grid Resilience and Assessment System (EGRASS)

Contact: Kevin Schneider kevin.Schneider@pnnl.gov

EGRASS is an easy-to-use online tool (web and mobile versions) for map-based distribution system decision support. EGRASS connects users with scientific research and study results to aid decisions for recommending candidate technologies deployments to improve resiliency and reliability for the critical end-use loads.





Question it answers: Help me decide which critical loads need…

- ✓ Remote-Controlled Switches
- ✓ Reclosers
- ✓ Fault Location, Isolation, and Service Restoration (FLISR)
- ✓ Self-Healing System
- ✓ Standalone Backup Generation
- ✓ Microgrids

Target users

- ✓ Developers, engineers, or planners
- ✓ Researchers
- ✓ State or local policymakers

Relevance to PR

Developed for PR, built on Puerto Rico data. Under continuing development with new features being added.

Training available

In development, user interface is designed to aid the user

Open source

Not yet

Link

http://egrass-test.pnl.gov

0.1 0 0.1 0.2 0.3 0.4 mi

Legend

- Distribution_Line
- Hospitals
- Substations
- ports ports in Puerto Rico
- Airports
- Water_Treatment_Plant
- Police Station
- Shelter

Pacific Northwest
NATIONAL LABORATORY

Tools Overview

D. Tom Rizy
Email: dtom@ornl.gov
Phone: (865) 574-5203
Oak Ridge, Tennessee

ORNL Tools – user-driven and publicly available

Tool name	Data or tool ⇩	Brief Description	Question it answers	Users	Training available	Open source
EAGLE-I	Both	Provides monitoring of the energy infrastructure assets, reporting energy outages, displaying potential threats, and coordinating emergency response and recovery.	During an extreme event what critical infrastructure will be impacted? What is the current number of customers without power?	✓ Emergency responders ✓ Government personnel ✓ Industry, utility companies	User manuals	No
MADRA - Microgrid Assisted Design for Remote Areas	Data	Integration of modeling systems to provide a microgrid analysis platform capable of providing technical analysis for designers to make appropriate design decisions.	What is the most optimal design of a microgrid based on user's needs? What is the cost of a microgrid?	✓ Developers, engineers, or planners ✓ Researchers	User manuals, support forum, and installation instruction available	Yes
MOVARTI	Tool	Evaluates voltage/reactive power (VAR) issues	Where are or will be reactive power issues on the grid? What is the value of a VAR?	✓ Utility engineers and planners ✓ Researchers	Available upon request	No
GridEye/FNET	Tool	Unique wide-area grid monitoring network can captures electrical grid's dynamic performance continuously in real time and uses monitoring devices that are essentially GPS time synchronized single-phase phasor measurement units.	What is the health of the electric grid? What event triggered an outage? How do we validate our models?	✓ Developers, engineers, or planners ✓ Researchers ✓ Utility companies	User manuals, support forum, and data download steps online	No
THYME	Tool	Simulation tool using C++ for studying the interaction of controls, communications, and electro-mechanical dynamics in a power system.	How will loads impact the electric grid? How can I best utilize communication and sensor technologies?	✓ Developers, engineers, or planners ✓ Researchers	Available upon request	Yes

EAGLE-I

EAGLE-I provides capabilities for monitoring energy infrastructure assets, reporting energy outages, displaying potential threats to energy infrastructure, and coordinating emergency response and recovery. DOE provides EAGLE-I as a service to other Federal, State, and local Agencies and Departments and to first-responders in accordance with DOE's Emergency Support Function-12 (ESF-12) mission.

Question it answers

During an extreme event what critical infrastructure will be impacted?

What is the current number of customers without power?

Relevance to PR

Assist in coordinating emergency response and recovery during extreme events such as hurricanes.

Target users

- ✓ Emergency responders
- ✓ Government personnel
- ✓ Industry, utility companies

Training available

User manuals,

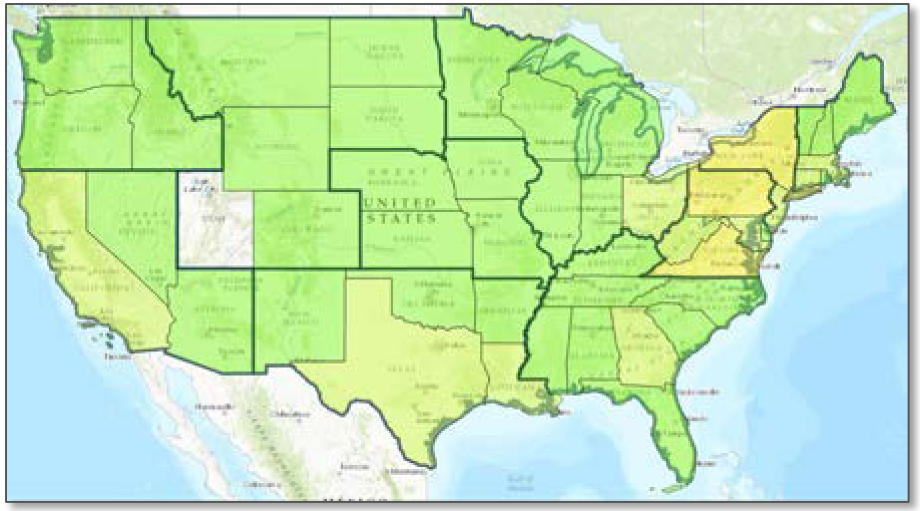
Open source

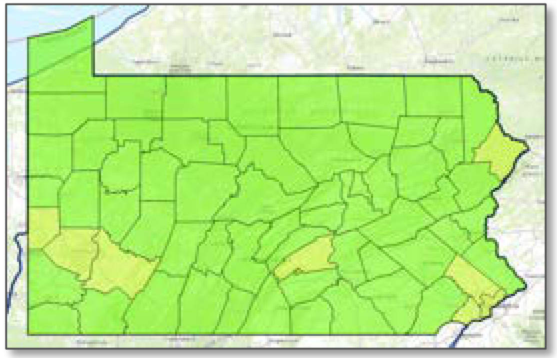
No

Link

https://eagle-i.doe.gov/login

Official use only





DOE's EAGLE-I, managed by ORNL, collects energy-sector infrastructure data into a real-time, shareable platform accessible via online portal

MADRA

MADRA is an integration of modeling systems to provide open source microgrid analysis platform for remote off- grid applications. This comprehensive design support tool for remote off-grid microgrids is capable of providing technical analysis for designers to make appropriate design decisions satisfying user-defined objectives and constraints for cost and reliability.

Question it answers

What is the most optimal design of a microgrid based on user's needs?

What is the cost of a microgrid?

Relevance to PR

Identify design and cost of deploying microgrids either with industrial stakeholders (PRIDCO) or through the utility company (PREPA)

Target users

- ✓ Developers, engineers, or planners
- ✓ Researchers

Training available

User manuals, support forum, and installation instruction available

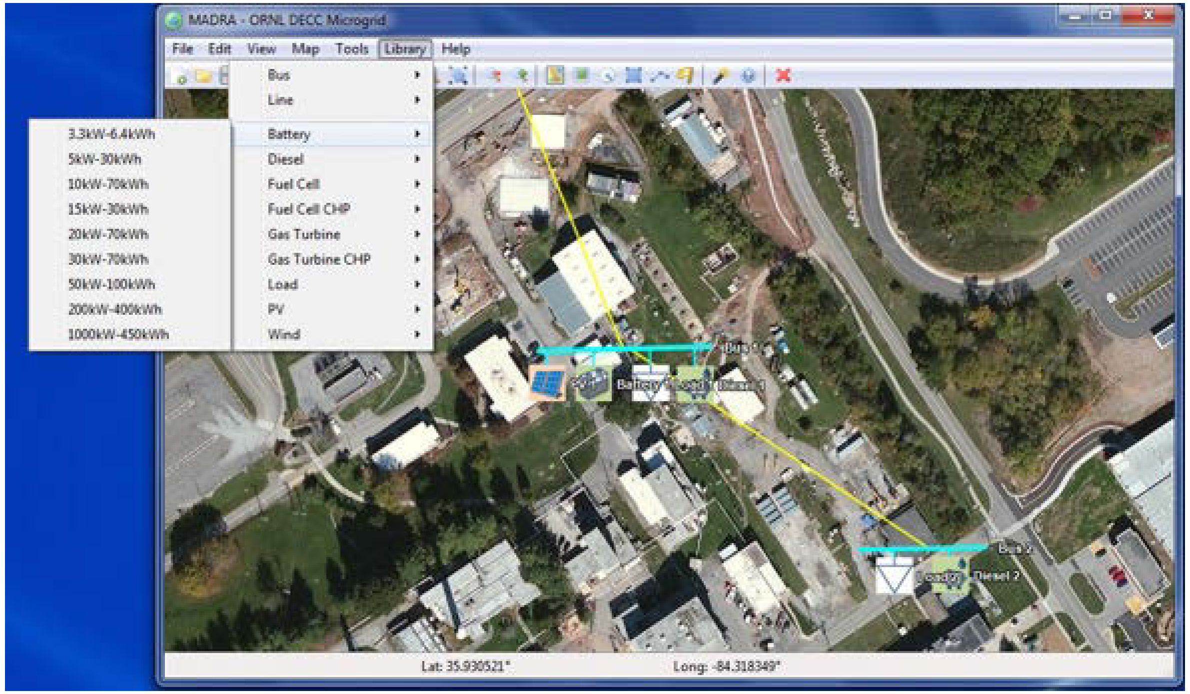
Open source

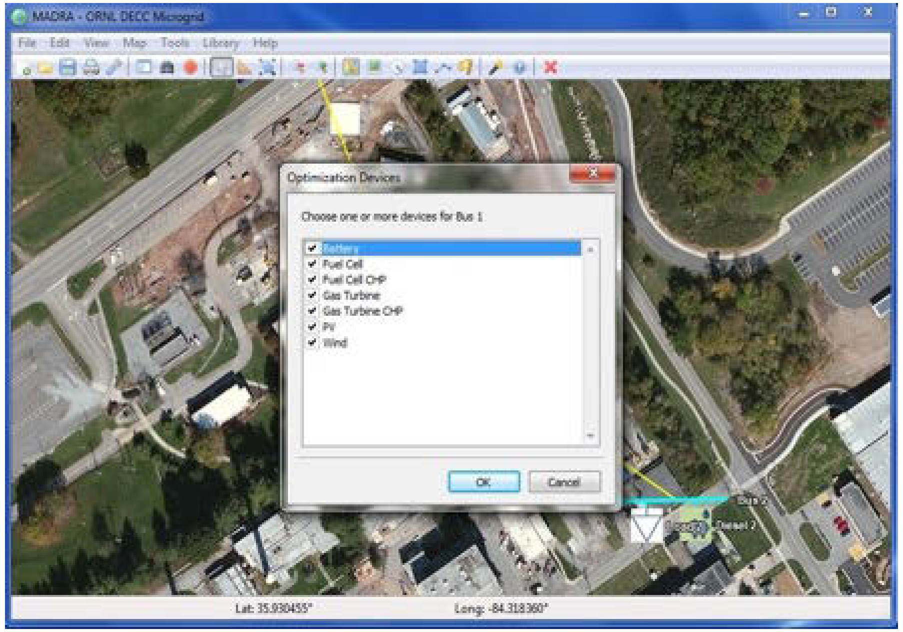
Yes

Link

https://daac.ornl.gov/SERVICES/guides/SDAT.html

Software can be delivered on request





A MADRA screen capture displaying the GIS Interface

MOVARTI

Management & Optimization of VARs for Future Transmission Infrastructure

MOVARTI is an integrated VAR planning tool that has several unique functions. User can identify VAR-related issues for existing and future power grids comprised of diversified generation sources especially the intermittent renewables, and/or with system topology/configuration changes. New voltage stability indices (VSI) can be defined to incorporate such generation diversity. The tool provides VAR size, location, and type (static or dynamic) planning solutions by performing multi- scenario static power flow and post-contingency dynamic voltage stability analysis. Additionally MOVARTI can perform VAR benefit analysis to assess the value streams of a VAR planning result or to find the optimal solution of VAR source investment with constraint budget.

Question it answers

Where are or will be reactive power issues on the grid?

What is the value of a VAR?

Relevance to PR

Help energy planners choose optimal locations for generation systems and understand future reactive power issues

Target users

- ✓ Utility engineers and planners
- ✓ Researchers

Training available

Available upon request

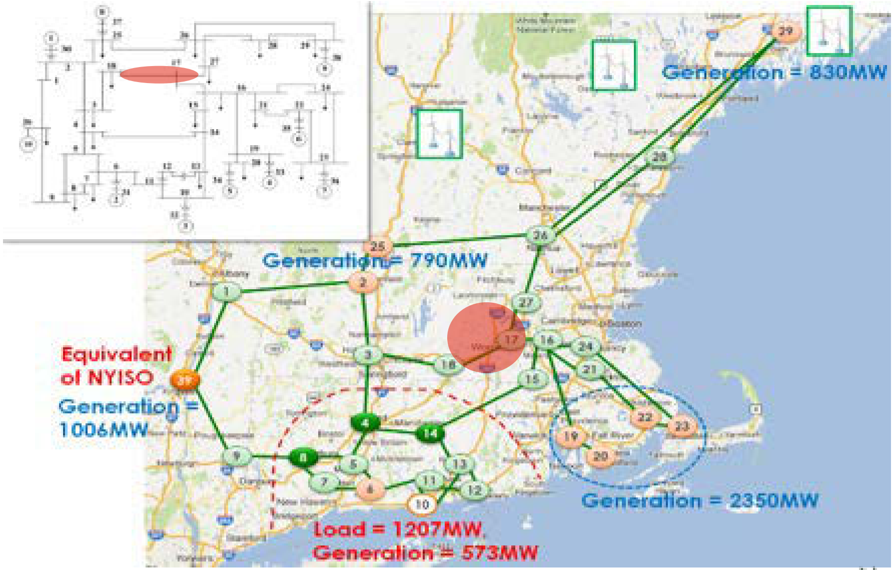
Open source

No

Link

https://web.ornl.gov/sci/renewables/docs/factsheets/MOVARTI-factsheet.pdf

MOVARTI tool



OAK RIDGE National Laboratory

GridEye/FNET

GridEye is a unique wide-area grid monitoring network that provides independent observation of the entire electrical grid's dynamic performance continuously and in real time. FNET/GridEye uses monitoring devices that are essentially GPS time synchronized single-phase phasor measurement units (or PMUs) to capture the dynamic responses (frequency, voltage and phase angle) of the grids to major disturbances such as generator trips and load shedding, as well as provide insight into inter-area oscillations. Since the monitors (which are referred to as frequency disturbance recorders, or FDRs) are connected at 110V, they do not require extensive installation as is the case for PMUs at high voltage substation.

Question it answers

What is the health of the electric grid?

What event triggered an outage?

How do we validate our models?

Relevance to PR

Currently being used to provide wide area situational awareness for PREPA.

Target users

- ✓ Utility companies
- ✓ Developers, engineers, or planners
- ✓ Researchers

Training available

User manuals, support forum, and data download steps online

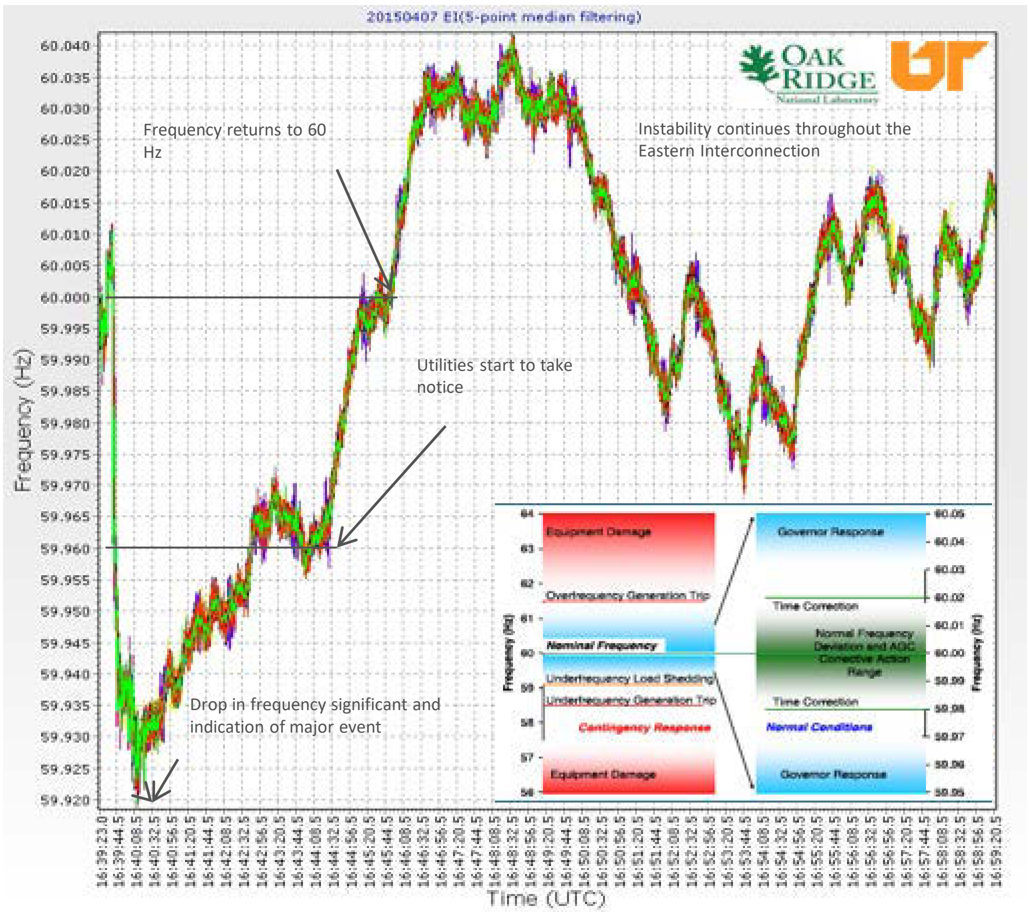
Open source

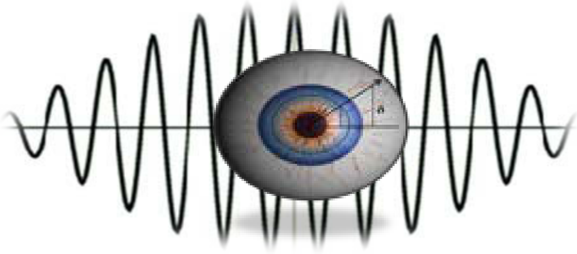
No

Link

https://web.ornl.gov/sci/renewables/docs/factsheets/FNET-GridEye-Factsheet.pdf

http://fnetpublic.utk.edu





THYME

Toolkit for Hybrid Modeling of Electric Power Systems

THYME is an open source simulation tool for studying the interaction of controls, communications, and electro-mechanical dynamics in a power system. This is not a simulation package like PSS/E, PSLF, and other similar, power system simulators. THYME is C++ library for building simulators that integrate its modules for power system dynamics with existing simulators for communication networks, discrete control systems, and discrete event simulation packages in general.

Question it answers

How will loads impact the electric grid?

How can I best utilize communication and sensor technologies?

Relevance to PR

Assist in the modeling of power system and communication networks on the island. Also aid in impact and use of specific communication technologies

Target users

- ✓ Developers, engineers, or planners
- ✓ Researchers

Training available

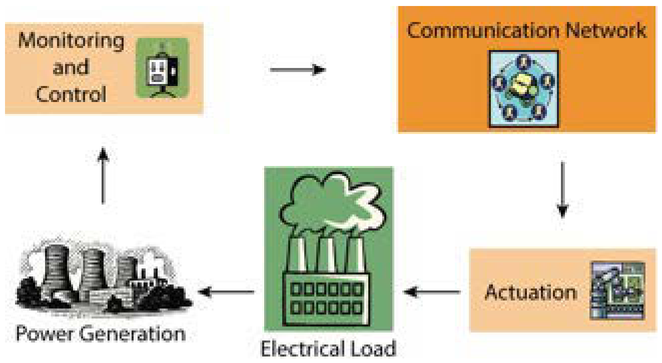
Available upon request

Open source

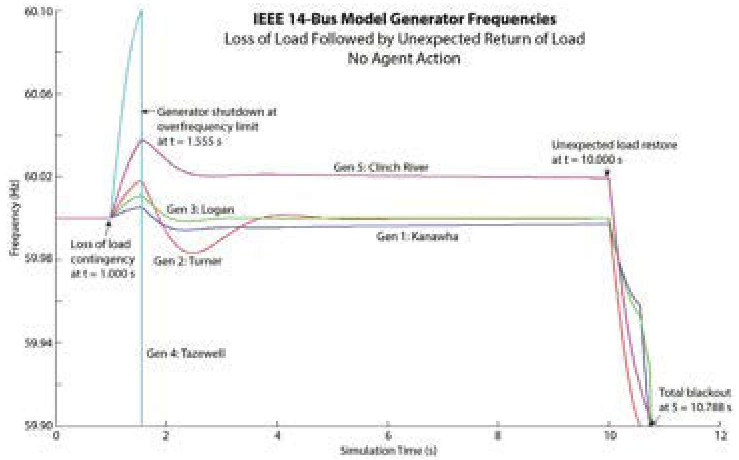
Yes

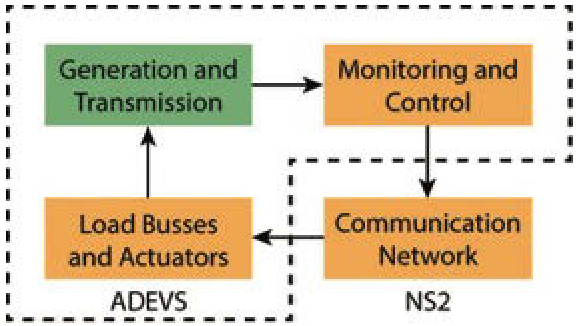
Link

https://web.ornl.gov/~nutarojj/thyme/docs/



Wide area monitoring and control of electric power systems





ORNL Tools – user-driven and publicly available

Tool name	Data or tool ⇩	Brief Description	Question it answers	Users	Training available	Open source
AutoBEM	Tool	Software suite for automatic detection and creation of Building Energy Models for any area of interest. Involves the semi-automated retrieval of data sources, computer vision, analysis, model creation, simulation, and analysis in a way that is replicable across cities	What is the technical potential for a utility to determine how much DSM potential is available at any time? How much energy efficiency potential is available for a given region?	✓ Developers, engineers, or planners ✓ Researchers	Available upon request	No
CoNNECT - Citizen Engagement for Energy Efficient Communities	Both	Community-based computational framework that enables consumers to benchmark their consumption against peers. It uses energy usage data (utility smart meter data) as well as property and spatial data from county government offices.	How can a community more effective utilize its energy? How can we accelerate the adoption of new technologies?	✓ Utility companies ✓ City council, community leaders ✓ Service organizations	Available upon request	No
Visual- SOLAR		Aids utilities by evaluating how PV DG could help address peak shaving and postpone infrastructure upgrades.	How can a community more effective utilize its energy? How can we accelerate the adoption of new technologies?	✓ Utility companies ✓ Residential communities ✓ Developers	Available upon request	No
ORCED - Generation Economic Modeling and Dispatch	Tool	Dispatches power plants in a region to meet electricity demands for any given year by matching generation to demands.	What are the impacts to emissions under different generating scenarios? How will dispatch impact costs and emissions?	✓ Developers, engineers, or planners ✓ Researchers	Available upon request	No
OR-SAGE - Oak Ridge Siting Analysis for Power Generation Expansion	Both	Dynamic visualization database employing GIS data and spatial modeling techniques to examine potential siting options for different electric generation and ramifications of national/regional energy policy decisions.	Where can we site new generation based on geo-spatial constraints? Can we attain certain energy goals based on future potential generation availability?	✓ Developers, engineers, or integrated resource planners ✓ Researchers ✓ Energy decision makers	Software operated at Oak Ridge National Laboratory	No

AutoBEM

Automatic Building Energy Model Creation

AutoBEM is a software suite for Automatic detection and creation of Building Energy Models for any area of interest which involves the semi-automated retrieval of data sources, computer vision, analysis, model creation, simulation, and analysis in a way that is replicable across cities. As an example, this has been applied to create and simulate over 130,000 building energy models with comparison to 15-minute data from every building within a municipality. This virtual utility is then analyzed assuming different technologies and policies to quantify energy, demand, emissions, and cost savings to inform operational decisions. The goal of this work is to create a freely available initial building energy model of every building in the United States.

Question it answers

What is the technical potential for a utility to determine how much DSM potential is available at any time?

How much energy efficiency potential is available for a given region?

Relevance to PR

Help energy planners choose optimal locations for generation systems and understand future reactive power issues

Target users

- ✓ Developers, engineers, or planners
- ✓ Researchers

Training available

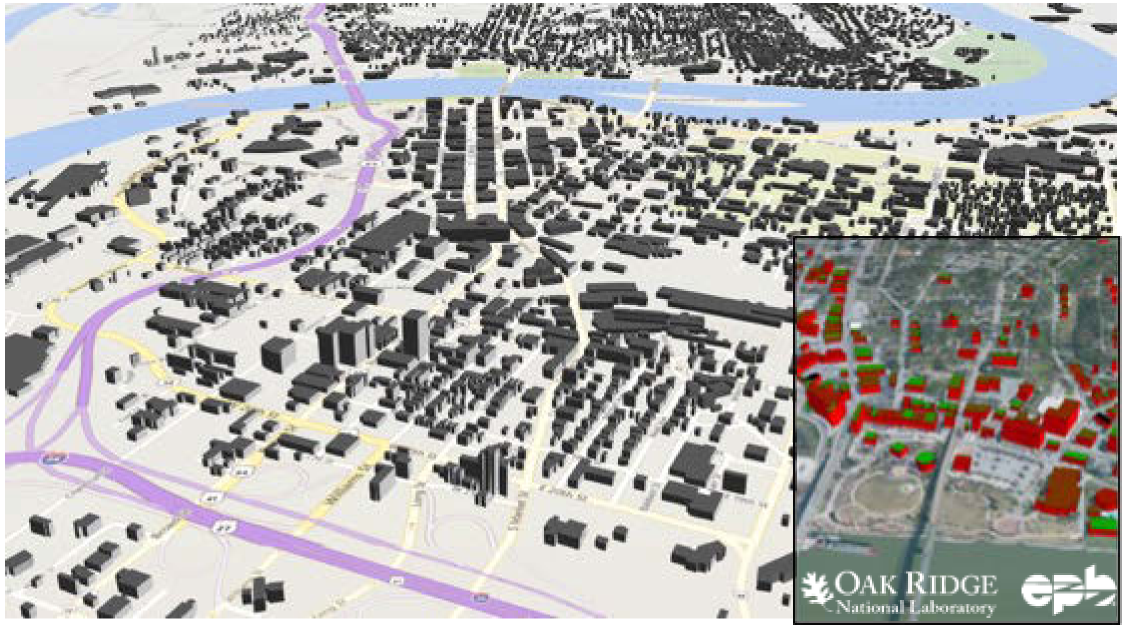
Available upon request

Open source

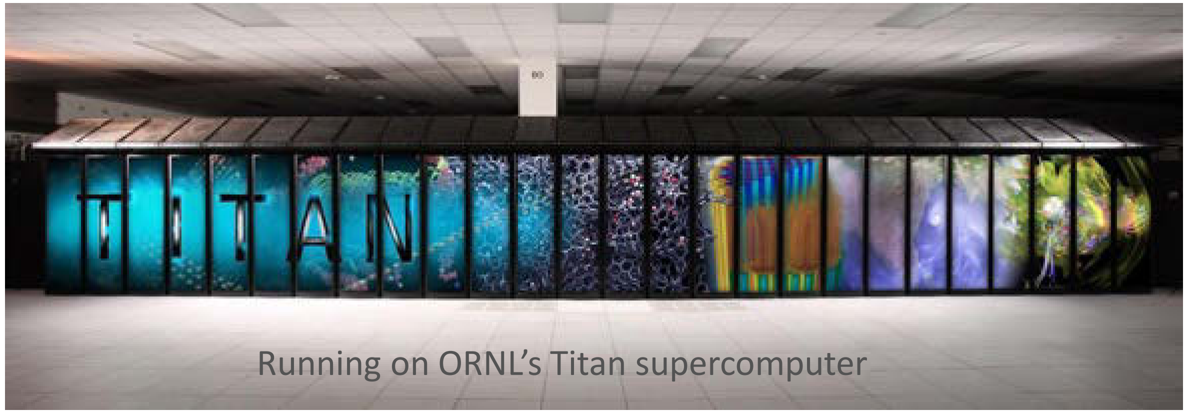
No

Link

https://evenstar.ornl.gov/autobem/virtual_epb/



Extracted geometry for 100,000+ buildings Interactive visualization on the web Create Building Energy Models



Running on ORNL's Titan supercomputer

CoNNECT

Citizen Engagement for Energy Efficient Communities

CoNNECT is a community-based computational framework that enables consumers to benchmark their consumption against that of their peers. This multi-partner platform, established to facilitate consumer engagement for energy efficiency, utilizes energy usage data, including the smart meter data from utilities as well as property and spatial data from county government offices and creates an interactive platform to better manage energy.

Question it answers

How can a community more effective utilize its energy?

How can we accelerate the adoption of new technologies?

Relevance to PR

Help the community provide awareness of energy best practices that can be critical prior and post extreme events.

Target users

- ✓ utility companies
- ✓ city council, community leaders,
- ✓ service organizations

Training available

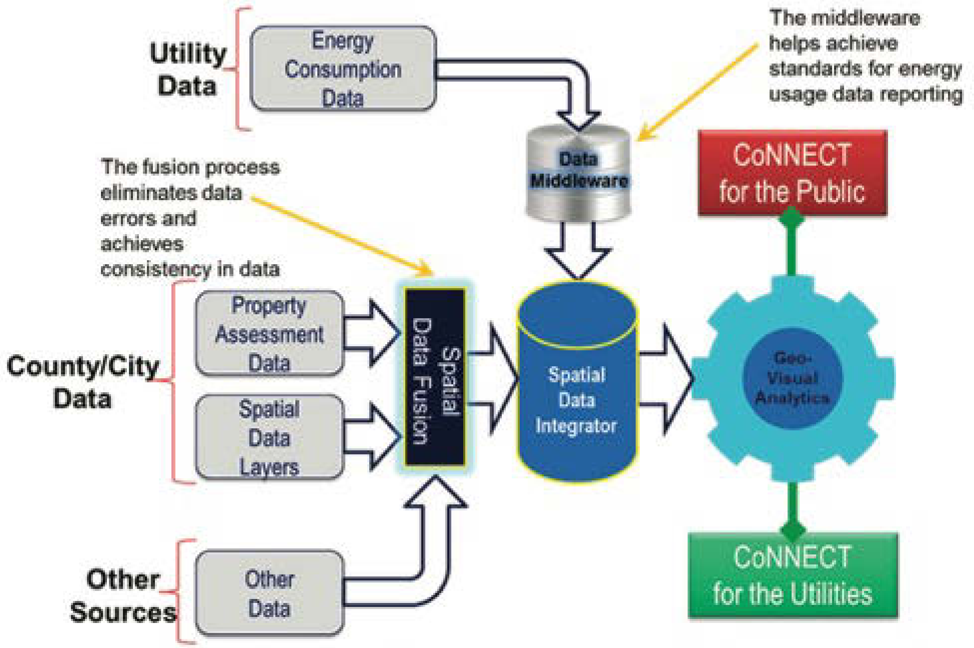
Available upon request

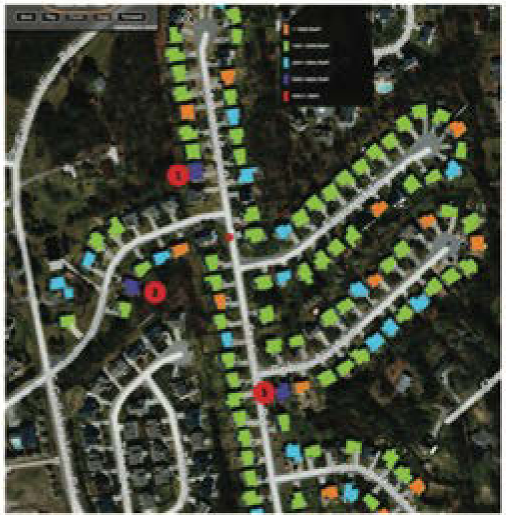
Open source

No

Link

https://info.ornl.gov/sites/publications/Files/Pub36731.pdf





Visual SOLAR

Visual-SOLAR – Visualizing Solar Radiation Potential on Building Rooftops: The *unique* application of Visual-SOLAR is aiding utilities to evaluate how PV distributed generation could help address peak shaving and postpone infrastructure upgrade within their service areas by taking advantage of solar radiation potential on their customers' building rooftop. The time required to perform the analysis could be reduced from months to minutes thereby greatly reducing the up-front planning cost of solar deployment at the utility level. For the residential and commercial customers, Visual-SOLAR helps individual building owner or a group of owners (in a co-op setting) to evaluate solar energy potential available to off-set some of their current electricity consumption.

Question it answers

How can a community more effective utilize its energy?

How can we accelerate the adoption of solar technologies

Relevance to PR

Provide technical potential of solar rooftop generation that can provide more generation diversity on the island

Target users

- ✓ utility companies
- ✓ Residential communities
- ✓ Developers

Training available

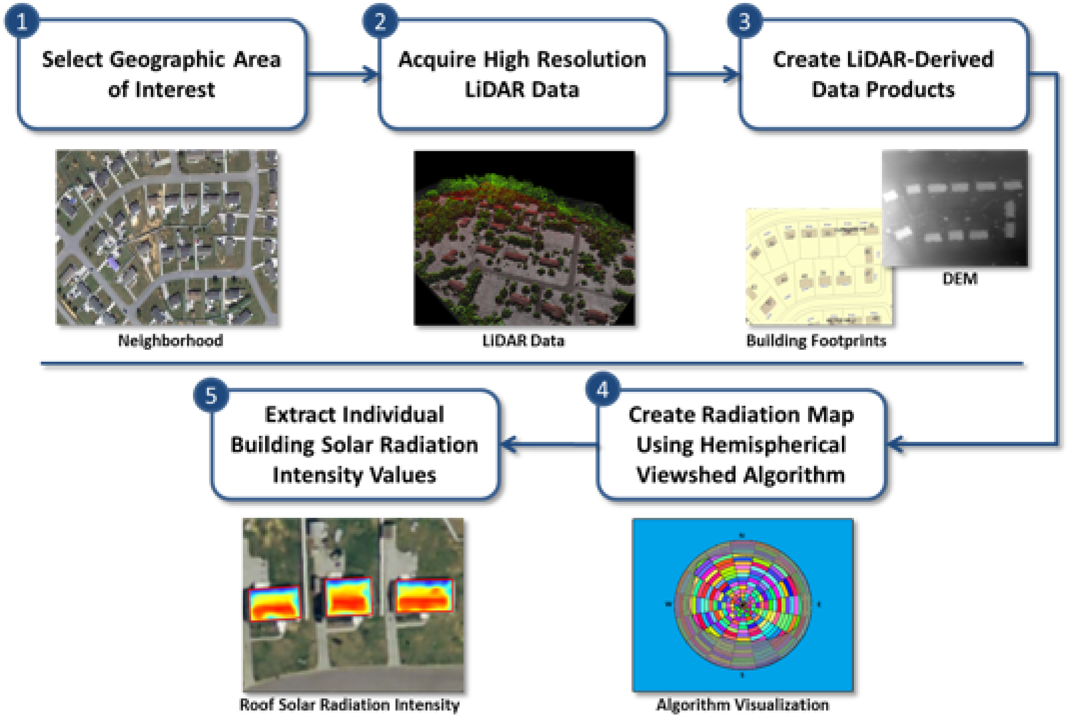
Available upon request

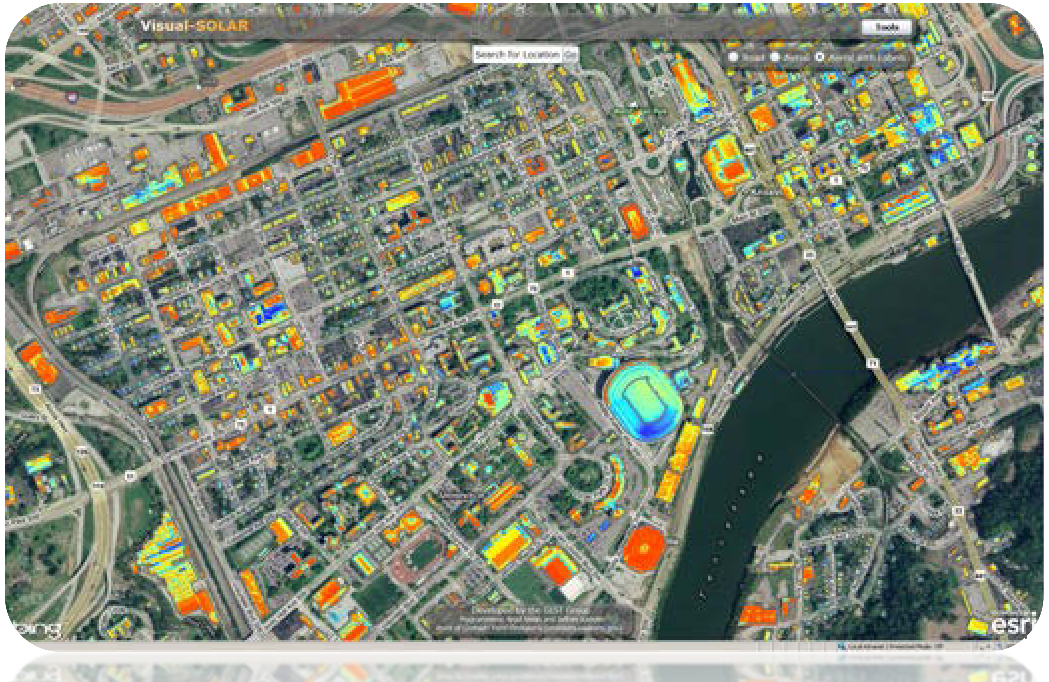
Open source

No

Link

http://gistbeta2/visual_solar/





ORCED

ORCED dispatches power plants in a region to meet electricity demands for any given year up to 2030. The model simulates a single region of the country for a given year, matching generation to demands. ORCED can calculate a number of key financial and operating parameters for generating units. It has been used in a variety of grid studies.

Question it answers

What are the impacts to emissions under different generating scenarios?

How will dispatch impact costs and emissions?

Relevance to PR

Calculate a number of key financial and operating parameters for generating units, including average and marginal prices, air emissions, and generation adequacy.

Target users

- ✓ Developers, engineers, or planners
- ✓ Researchers

Training available

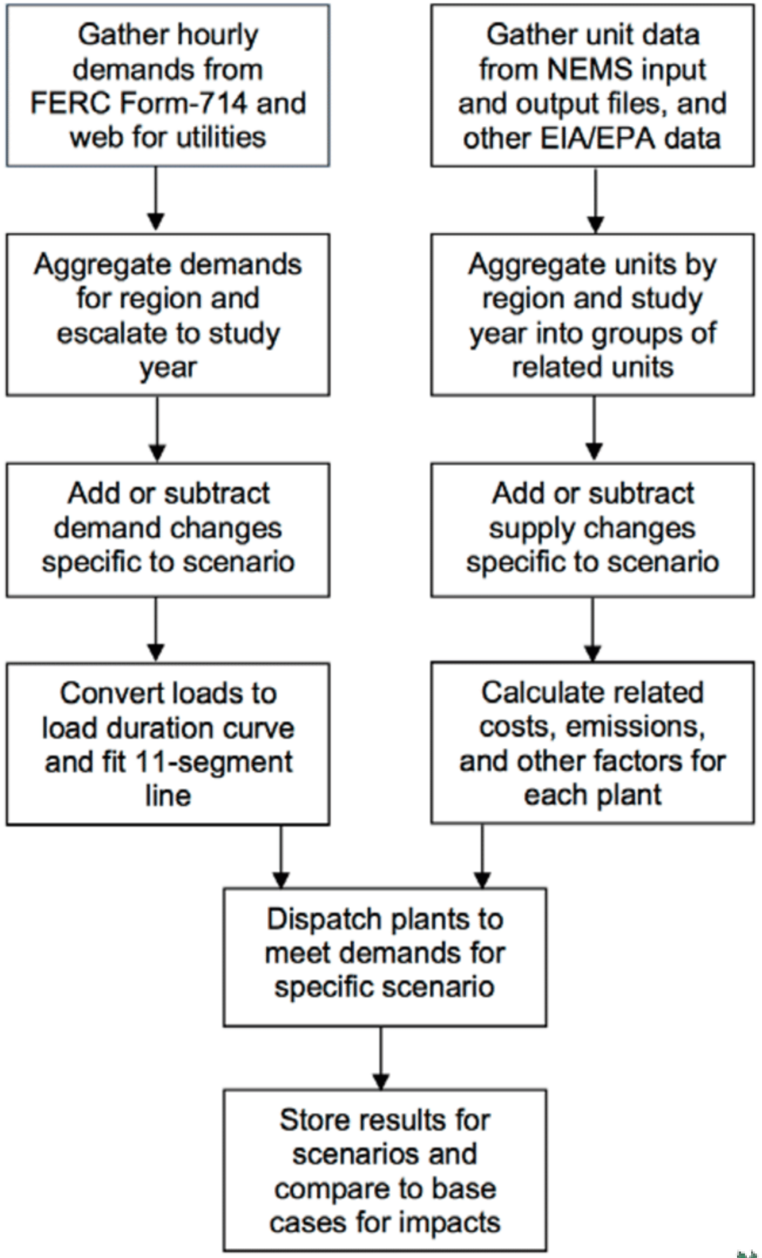
Available upon request

Open source

No

Link

https://ornl.sharepoint.com/sites/eesd_programs/electricdelivery/Reports/ORCED%20ModelFinal.pdf#search=ORCED



ORCED Flow Diagram

OR-SAGE

OR-SAGE

The OR-SAGE tool is a dynamic visualization database employing both geographic information systems (GIS) data and spatial modeling techniques used at ORNL to examine both potential siting options for different types of electrical generation plants and ramifications of national & regional energy policy decisions.

Question it answers

Where can we site new generation based on geo-spatial constraints?

Can we attain certain energy goals based on future potential generation availability?

Relevance to PR

Help energy planners choose optimal locations for generation systems and understand future power issues

Target users

- ✓ Developers, engineers, or integrated resource planners
- ✓ Researchers
- ✓ Energy decision makers

Training available

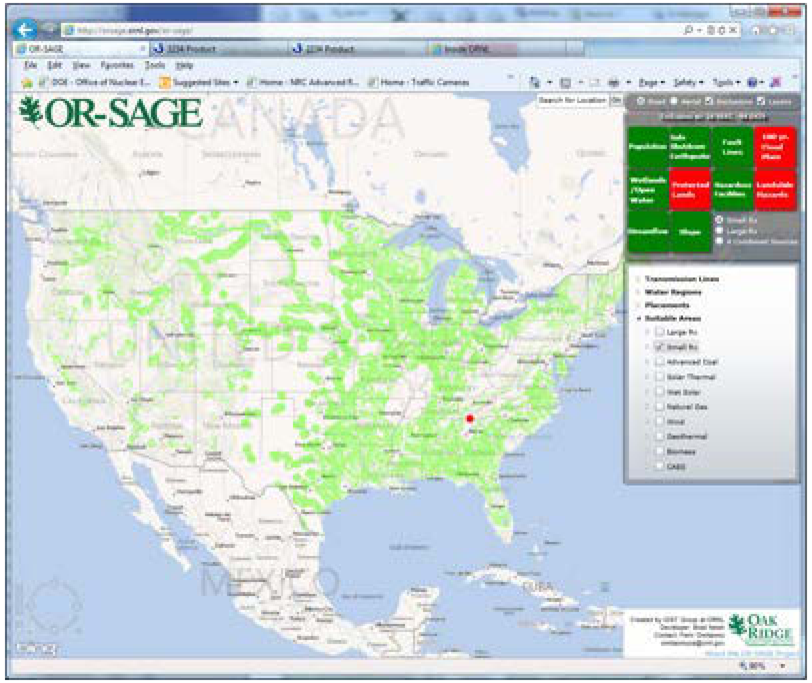
Software operated at Oak Ridge National Laboratory

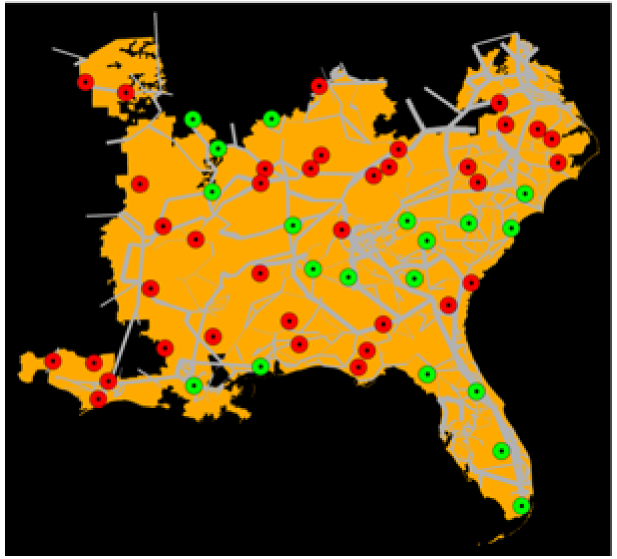
Open source

No

Link

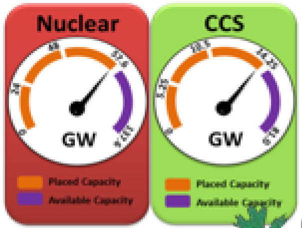
www.osti.gov/servlets/purl/1032036/





Southeast Region Achieves 81% Clean Energy Mix

SOUTHEAST REGION	Nuclear	Clean Coal	Concentrated Solar
Capacity (GWe) to Meet Presidential 80% Clean Energy Goal	57	14	0



OR-SAGE functions as a visual database

ORNL Tools – user-driven and publicly available

Tool name	Data or tool ⇩	Brief Description	Question it answers	Users	Training available	Open source
CSEISMIC - Complete System-level Efficient, Interoperable Solution for Microgrid Integrated Controls	Tool	Monitors and controls microgrid components through communication links to perform both real-time controls and energy management. Also, provides the interface between the microgrid and the power system operator/energy market	What systems can be used to operate a microgrid? How do we control networked microgrids?	✓ Utility engineers, or planners ✓ Microgrid developers ✓ Researchers	Software can be downloaded from website; training available upon request	Yes
SI-GRID	Tool	Open research platform to safely test microgrid components in low-voltage settings (below 100 volts) that mimic real-world, high-voltage applications.	What novel control architectures can be used in the grid? How can I verify new protection schemes will not negatively impact the grid?	✓ Developers, engineers, or planners ✓ Researchers	Software can be downloaded from website; training available upon request	Software is open source
SPOT – Sensor Placement Optimization Tool	Both	Platform for optimizing sensor placement strategy to enhance distribution system monitoring and resiliency. It allows the utility stakeholders to meet the monitoring and control requirements with less cost while satisfying practical constraints.	How to determine the optimal sensor strategy (types, number and locations) when planning new sensors and reclosers?	✓ Utility companies ✓ Developers, engineers, or planners ✓ Researchers	User manuals, training available upon request	No

CSEISMIC

Complete System-level Efficient and Interoperable Solution for Microgrid Integrated Controls (CSEISMIC). It monitors and controls the microgrid components through communication links to perform both real-time controls and energy management. It is also the interface between the microgrid and the power system operator/energy market for the microgrid to participate in system operation and/or energy market activities.

Question it answers

What systems can be used to operate a microgrid?

How do we control networked microgrids?

Relevance to PR

Currently being used in Southern Company's Connected Community Neighborhood. Similar framework could be used in Puerto Rico

Target users

- ✓ Utility engineers, or planners
- ✓ Microgrid developers
- ✓ Researchers

Training available

Software can be downloaded from website; training available upon request

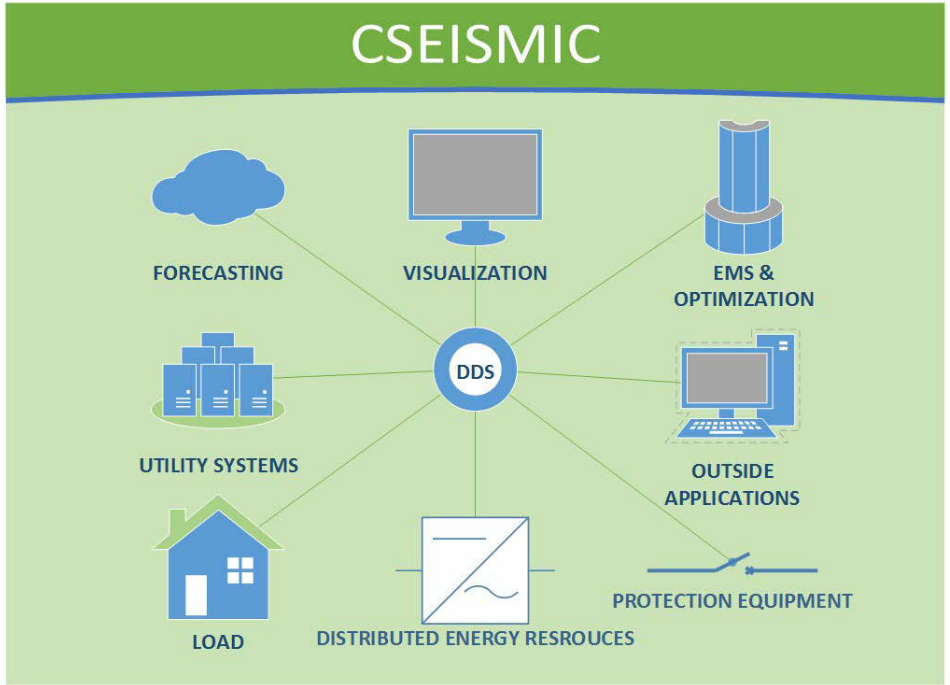
Open source

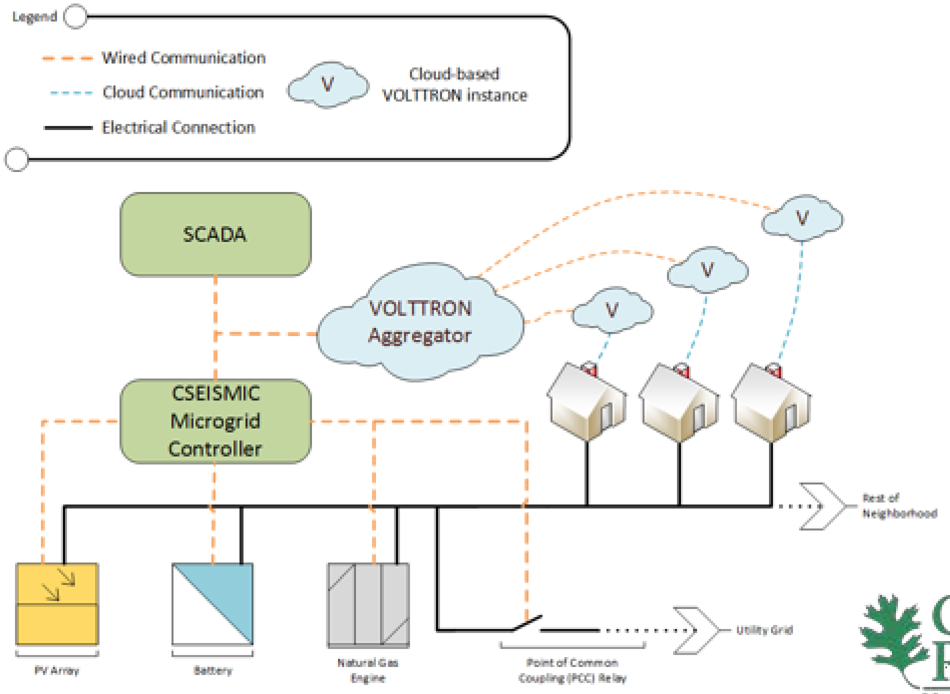
Yes

Link

https://github.com/ORNLPES/CSEISMIC

https://web.ornl.gov/sci/renewables/docs/factsheets/CSEISMIC-factsheet.pdf





SI-GRID

Software-Defined Intelligent Grid Research Integration and Development

SI-GRID is an ORNL-developed open research platform to safely test microgrid components in low-voltage settings (below 100 volts) that mimic real-world, high-voltage applications. The system is accelerating science from the lab to the field. It can, for instance, test protective relays that detect electrical faults and prevent damage to the network. The platform is being used to develop and rapidly prototype technologies associated with microgrids, including power electronics–based converters, generation technologies, energy storage, protection, cybersecurity methods, communications protocols, control, optimization, standardization, and integration of DERs, buildings, and vehicles.

Question it answers

What novel control architectures can be used in the grid?

How can I verify new protection schemes will not negatively impact the grid?

Relevance to PR

Provides an environment to demonstrate advanced control schemes prior to deploying in the field with more resolution

Target users

- ✓ Developers, engineers, or planners
- ✓ Researchers

Training available

Software can be downloaded from website; training available upon request

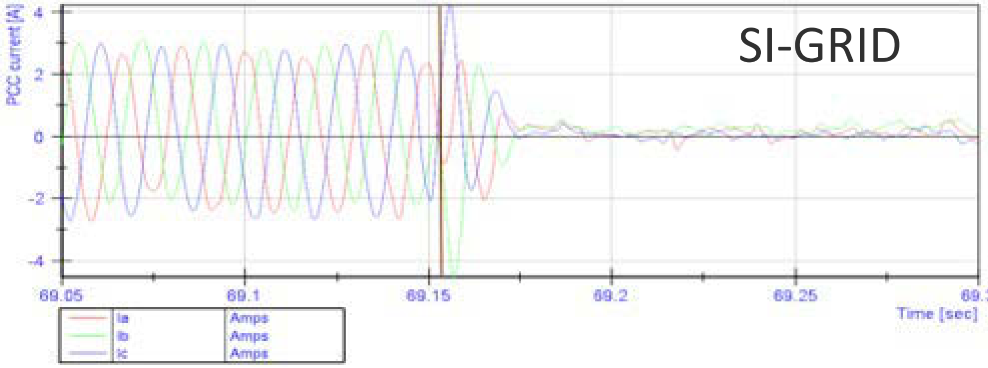
Open source

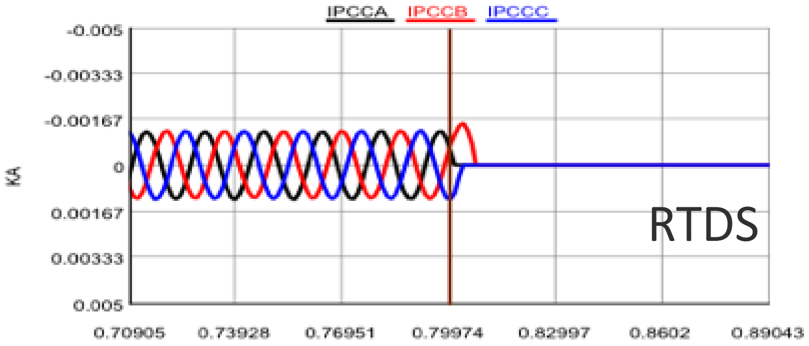
Software is open source

Link

https://github.com/ORNLPES/

Step in-between HIL and full-scale testing





SPOT

Sensor Placement Optimization Tool

SPOT- Sensor Placement Optimization Tool is a platform for optimizing the sensor placement strategy to enhance distribution system monitoring and resiliency. It allows the utility stakeholders to meet the monitoring and control requirements with less cost and satisfying practical constraints. It contains two selected modules currently based on industry priority: distribution state estimation (DSE) module and recloser placement module. The three-phase feature is captured in DSE module to reflect practical distribution systems with asymmetrical topology and unbalanced load. Also, the impact of microgrid is modeled in recloser placement module. SPOT can help utility stakeholders develop their own optimal sensing strategies.

Question it answers

How to determine the optimal sensor strategy (types, number and locations) when planning new sensors and reclosers?

Relevance to PR

Can optimize sensor placement strategy and help utility stakeholders develop their own optimal sensing and measurement strategies and roadmaps

Target users

- ✓ Utility companies
- ✓ Developers, engineers, or planners
- ✓ Researchers

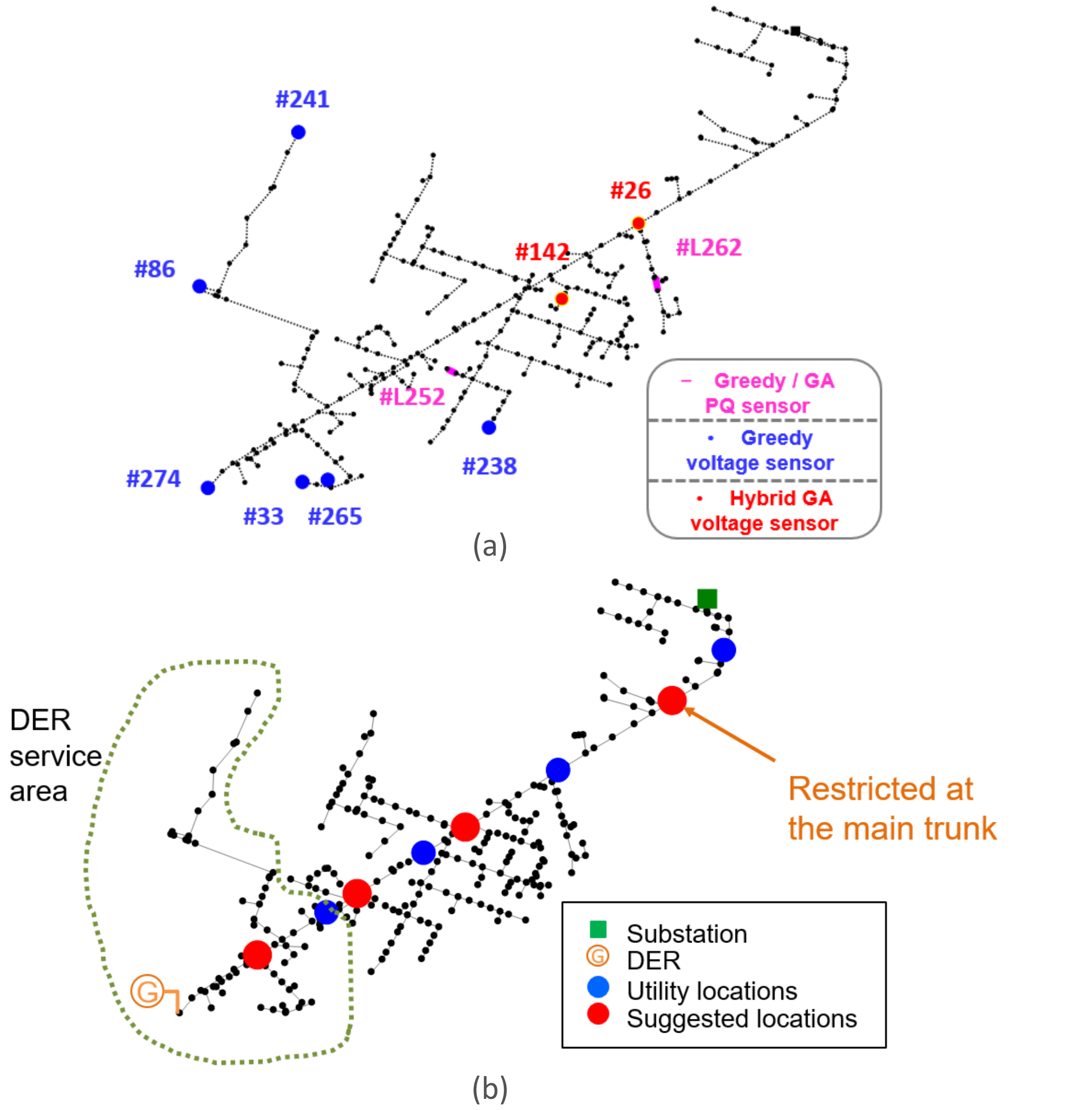
Training available

User manuals, training available upon request

Open source

No

Link

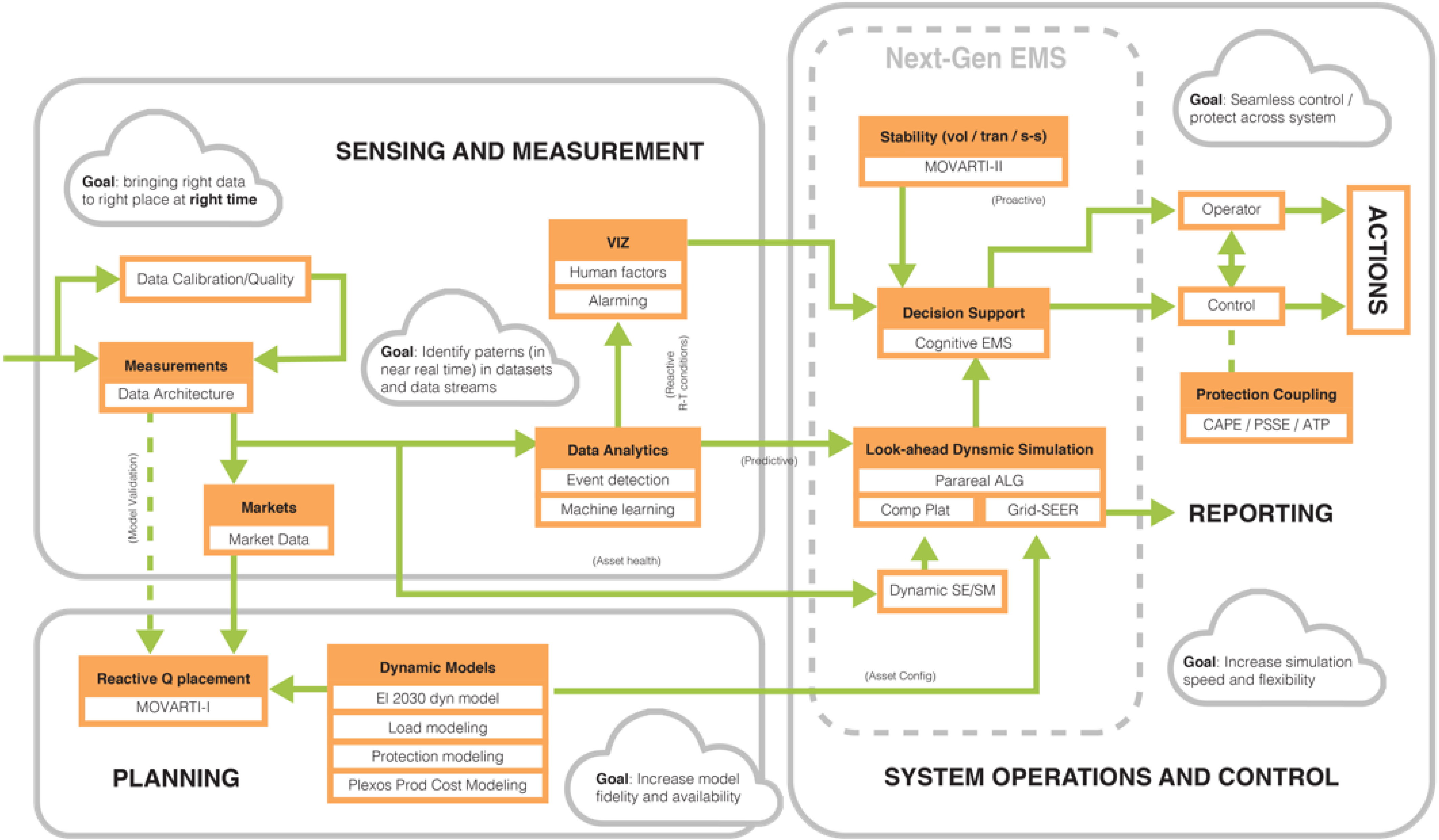


Use cases on a realistic feeder : (a) DSE module (b) recloser placement module

ORNL Tools – commercial tools used

Tool name	Data or tool ⇩	Brief Description	Solution it provides	Training available	Open source
CAPE – Siemens Computer Aided Protection Engineering	Tool	A tool for modeling electric utility protection systems. The tool comes with a large library of detailed relay models (over 6,000 relay styles, reclosers, and fuses) and the ability to add new relay models.	CAPE is built for engineers responsible for protection of high-voltage transmission systems and distribution systems within electric utilities and provides them with advanced tools for network and protection simulation.	Yes	No
PSS/E – Siemens Power System Simulator for Engineering	Tool	PSS/E is an integrated, interactive program for simulating, analyzing, and optimizing power system performance.	It provides advanced and proven methods in many technical areas, including: Power Flow, Optimal Power Flow, Balanced or Unbalanced Fault Analysis, Dynamic Simulation, Extended Term Dynamic Simulation, Transfer Limit Analysis, Network Reduction.	Yes	No
PSLF - GE Positive Sequence Load Flow Software	tool	PSLF is a suite of analytical tools that can simulate large-scale power systems up to 60,000 buses.	This power systems analysis package includes programs for load-flow, short-circuit, and transient-stability simulations.	Yes	No
POM – V&R Physical and Operational Margins	Tool	Powerful and highly automated power systems engineering application used for the steady-state stability analysis.	The tool includes load flow, AC contingency analysis, power transfer, and voltage stability analyses.	Yes	No
PowerWorld Simulator	Tool	PowerWorld Simulator is an interactive power systems simulation package designed to simulate high voltage power systems operation on a time frame ranging from several minutes to several days.	The software contains a highly effective power flow analysis package capable of efficiently solving systems with up to 100,000 buses.	Yes	No
ATF (Alternative Transients Program) **& EMTP** (Electromagnetic Transients Program)	Tool	A universal program for digital simulation of transient phenomena of electromagnetic as well as electromechanical nature.	With this program, complex networks and control systems of arbitrary structure can be simulated. The program is being used to model the impact of high efficiency heat pumps on the electric distribution system.	Yes	No
RiverWare	Both	ORNL has prepared RiverWare water-constrained energy production models for hydro- systems across the U.S., including models of hourly coordination of mid-Columbia River hydropower generation and models of daily hydro-system generation in the Hudson (NY) and Penobscot (ME) Basins.	Modeling of time-varying maximum and minimum capabilities of hydraulically-connected generation facilities within power system dispatch.	Yes	No

ORNL Advanced Grid Modeling



OAK RIDGE National Laboratory

Sandia National Laboratories

Dan Borneo

Sandia National Laboratories

Sandia Grid Resilience Tools for Puerto Rico

PRESENTED BY

Dan Borneo

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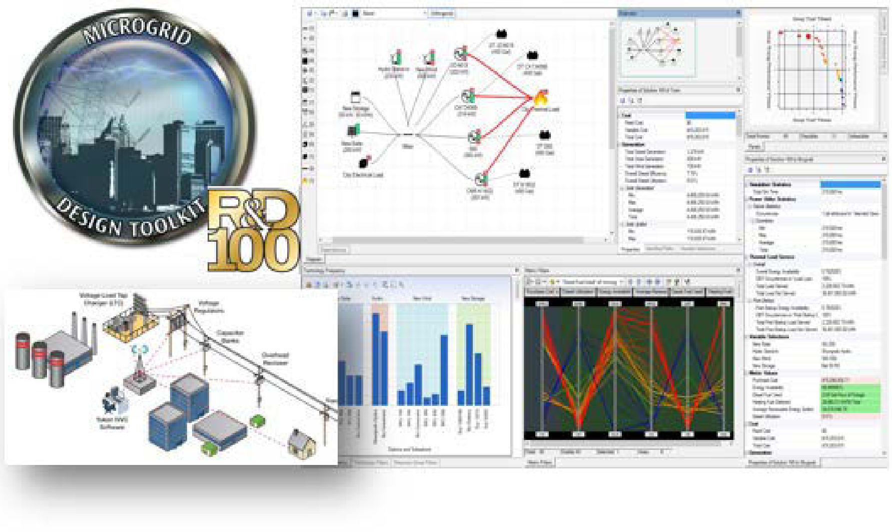
Microgrid Design Toolkit (MDT): Design Optimization and Cost-Performance Trade-off



Model details:

Name: Microgrid Design Toolkit

Type: Multi-objective optimization decision support tool for electric systems design, based on cost, reliability and availability targets

Source: Sandia, DOE/DOD co-sponsored. development

Update/availability: 2018 software, documentation, model library and use cases public download available from DOE website

Compatibility/Implementation:

Computational: Runs on PC/workstation. HPC may be required depending on system scale

RT application: Not HIL-enabled, but could be implemented through co-simulation

Uncertainty: Explicit representation of uncertain/stochastic parameters (e.g., failure probabilities). Load-generation balance handled via time-series dispatch analysis.

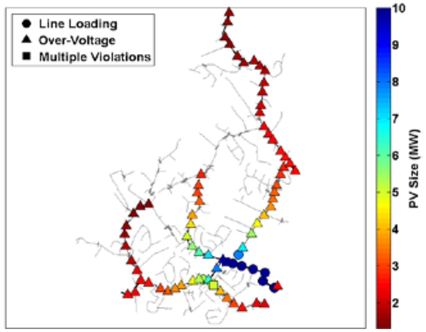
Proposed Application to Resilience Modeling:

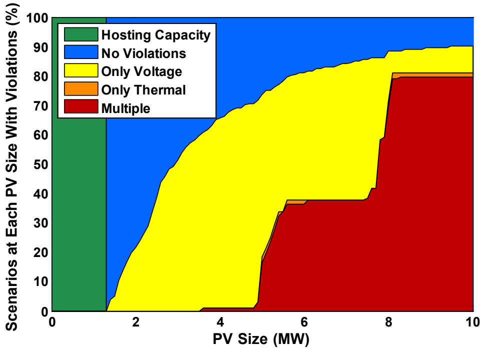
Scope: Optimizes investment options for energy systems, primarily designed for microgrids, using computationally efficient heuristics.
Processes modeled: Models network, load, storage and generation elements and their respective failure rates and mechanism.
Application: Reliability/resilience analysis of energy systems. Has been extensively applied to civilian and military microgrid design to maximize cost-benefit.

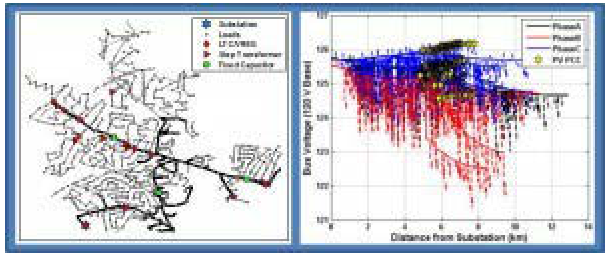
- Military: SPIDERS, numerous DOD energy surety assessments
- Civilian: Urban, Transportation, and Industrial microgrids

Contact: Abraham Ellis, 505-844-7717, aellis@sandia.gov

PV Performance Modeling Collaborative







Model details:

Name:

PV_LIB Toolbox – PV performance modeling functions available in Matlab and Python

GridPV Toolbox – A tool for modeling power flow and voltage patterns on distribution feeders with PV

PV Variability Datasets – A collection of high frequency (1 -30 sec) irradiance data samples across the US

Wavelet Variability Model – A model for estimating the variability in PV plant output based in point sensors of irradiance and PV plant geometry.

Source: Sandia National Laboratories

Documentation: https://pvpmc.sandia.gov/

Compatibility/Implementation:

Computational: HPC not normally required (reduced order)

RT application: Can be adapted to Real-Time simulations

Stochastic/Uncertainty: Deterministic model parameters, but uncertainty can be explored via Monte Carlo analysis

Compatibility: Fully compatible with standard distribution system simulation packages (e.g., Cyme, OpenDSS as well as MATLAB)

Proposed Application to Resilience Modeling:

Scope: Tools for modeling PV plant output as well as distribution system performance with various distributed energy resource (DER) penetrations.

Processes modeled: Irradiance->Cell model->Inverter Model->Distribution level model

Application: Model DER penetrations and the impact on the distribution grid (e.g., voltage, current, and thermal violations). Identify solar hosting capacity using quasi-static time series simulations (more accurate results than static analysis).

Contact: Abraham Ellis, 505-844-7717, aellis@sandia.gov

Energy Storage Optimization & Evaluation Tool - QuEST

Model details:

Software tool for energy storage researchers and stake holders:

- Free, open-source, easy-to-use
- Runs on Windows, Mac, or Linux
- Provides sophisticated back-end with optimization algorithms developed by researchers at Sandia and validated with numerous peer-reviewed publications
- Interfaces with other Sandia software tools such as Prescient (Production Cost Model Tool), Microgrid Design Tool (R&D 100 winner)

Prior Applications:

Internal use for analytical studies:

- Nguyen, Byrne, Concepcion, Gyuk. "Maximizing revenue from electrical energy storage in MISO energy & frequency regulation markets," 2017 IEEE Power & Energy Society General Meeting.
- Byrne, Hamilton, Borneo, Olinsky-Paul, Gyuk. "The value proposition for energy storage at the sterling municipal light department," 2017 IEEE Power & Energy Society General Meeting.
- Byrne, Concepcion, Silva-Monroy. "Estimating potential revenue from electrical energy storage in PJM," 2016 IEEE Power and Energy Society General Meeting.
- Byrne, Silva-Monroy. "Potential revenue from electrical energy storage in ERCOT: The impact of location and recent trends," 2015 IEEE Power & Energy Society General Meeting.

Proposed Application to Resilience Modeling:

Software tool allows users to:

- Analyze value of energy storage across the country
- Determine optimal sizing and placement
- Select appropriate technology
- Optimally design and manage microgrids

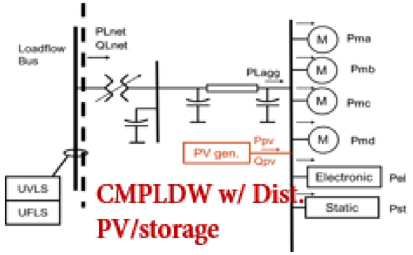
Outputs results that help users:

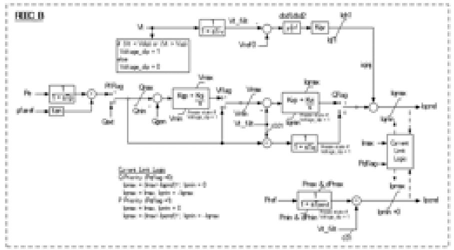
- Make investment/planning decisions
- Simulate use-cases
- Visualize data

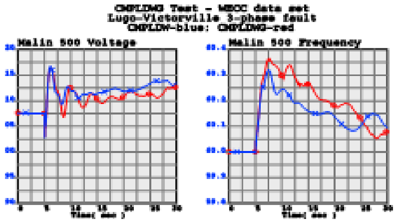
Available on Github: https://github.com/rconcep/snl-quest

Contact: Babu Chalamala, 505-845-7185, bchalam@sandia.gov

Standard Models for Distributed and Bulk-level Wind, Solar and Energy Storage







Model details:

Name: ***RExx*** for wind, solar, storage; ***CMPLDW*** for load

Type: Positive-seq. dynamic & power flow models

Source: Sandia-led WECC Renewable Energy Task Force and Modeling and Validation Working Group, input from DOE labs, manufacturers, utilities, sw. vendors

Update: TRL 8+, available in major simulation platforms

Documentation: www.wecc.biz

Compatibility/Implementation:

Computational: HPC not normally required (reduced order)

RT application: Can be adapted to Real-Time simulations

Stochastic/Uncertainty: Deterministic model parameters, but uncertainty can be explored via Monte Carlo analysis

Compatibility: Fully compatible with standard positive-sequence base cases and simulation platforms

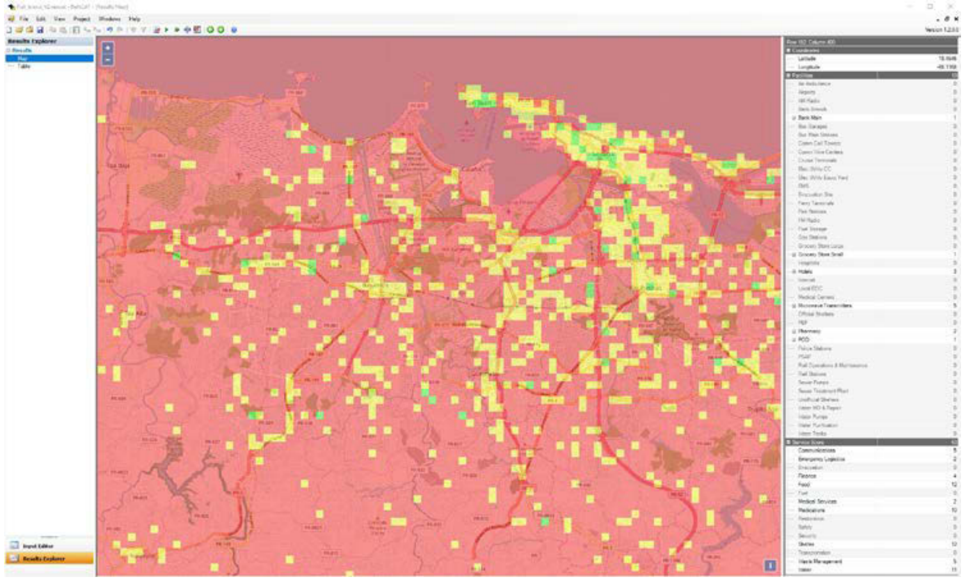
Proposed Application to Resilience Modeling:

Scope: ***RExx***: turbine and governor, Generator/converter and excitation. ***CMPLDW***: static and motor loads including single-phase stalling, and distributed PV and storage
Processes modeled: Dynamic stability of the bulk system, including recovery from severe disturbances
Application: Model centralized and distributed wind, solar and energy storage in transmission reliability/expansion and generation interconnection studies.

- Load/generation adjustable via power reference parameter
- Model documentation includes default parameter data, and suggested regional/seasonal variations.

Contact: Abraham Ellis, 505-844-7717, aellis@sandia.gov

ReNCAT



Model details:

Name: ***ReNCAT***

Type: Microgrid design (clustering) algorithm that minimizes societal burden with respect to various threats (e.g., flooding, hurricanes, earthquakes, etc.).

Source: Sandia National Laboratories

Update: will be released to the public in 2019

Documentation: N/A

Compatibility/Implementation:

Computational: HPC not normally required (reduced order)

RT application: Can be adapted to Real-Time simulations

Stochastic/Uncertainty: Deterministic model parameters, but uncertainty can be explored via Monte Carlo analysis

Compatibility: Fully compatible with distribution system models

Proposed Application to Resilience Modeling:

Scope: Microgrid design (clustering) algorithm that minimizes societal burden with respect to various threats (e.g., flooding, hurricanes, earthquakes, etc.).
Processes modeled: Societal benefits provided by critical infrastructure, threat impacts to various types of infrastructure, distribution grid topology and optimal partitioning into microgrids
Application: Top-down modeling process for identifying potential clusters of critical infrastructure for microgrids that are resilient with respect to the modeled threats. After this analysis, MDT is typically employed to size the microgrid components.

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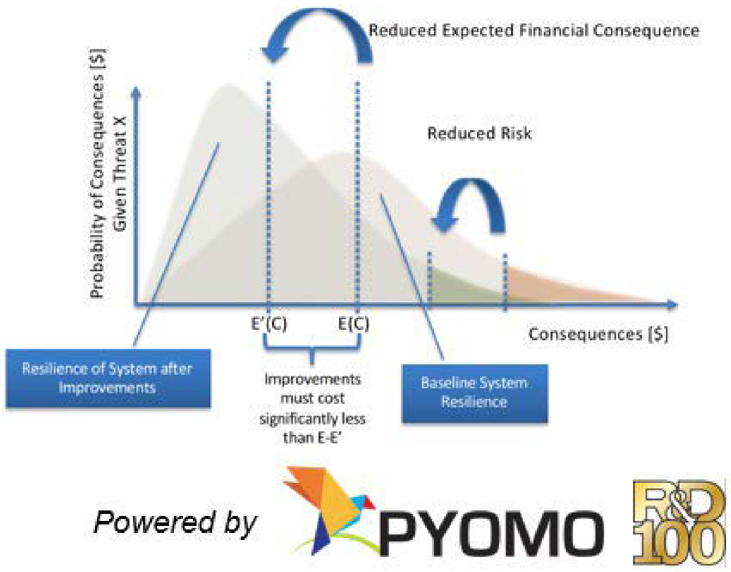
Grid Resiliency Open-Source Optimization Toolkit



Model details:

- Implements Sandia's Resiliency Analysis Process (RAP), highlighted in recent DOE QER and QTR
- Automatically identifies worst-case and near-worst-case transmission level attack vectors
- Automatically identifies mitigation strategies for extreme weather events
- Stochastic and robust transmission-level system optimization
- Power flow and dispatch-focused analyses
- Lab-developed, funded by DHS, DOE/OE, and DOE/EPSA

Prior Applications:

- Extreme weather mitigation for American Electric Power (AEP) - West
- Physical vulnerability assessment for American Electric Power (AEP) - East
- GMD mitigation for Pennsylvania-Jersey-Maryland Independent System Operator
- Model is under active development and extension (Advanced Grid Modeling program)
- In process of transitioning from internal Sandia tool to broader, open source deployment
- Model details informed by significant interactions with NERC and AEP

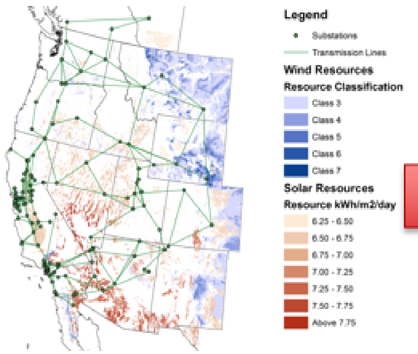
Proposed Application to Resilience Modeling:

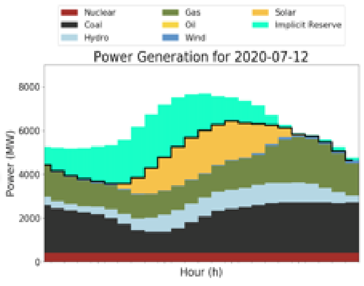
- Provide quantitatively rigorous scenarios for NERC GridEx and related operational exercises
- Provide regional vulnerability assessments concerning physical attack vectors
- Provide rate case justification for resiliency investments through reliability-resiliency co-optimization
- Primarily for planning purposes. Turn-around times within 30 minutes possible for operations situational awareness
- Leverages multi-core cluster resources, if available
- Uncertainty is inherent in the Resiliency Analysis Process, and is explicitly modeled
- Takes PSSE as standard input format for power flow cases

Contact: Raymond Byrne, 505-844-8716, rhbyrne@sandia.gov

Long-Term Grid Expansion Planning Under Uncertainty

TIGRIS: Generation and Transmission Expansion Co-Optimization





Powered by PYOMO R&D 100

Prescient: Production Cost Modeling

Model details:

- Transmission, generation, and storage co-optimization to ensure equitable treatment of alternative resources
- Fully integrated stochastic unit commitment and economic dispatch
- High-fidelity probabilistic treatment of solar and wind production
- Stochastic transmission level optimization
- Lab-developed, funded by DOE/SC, DOE/ARPA-E, and DOE/OE
- Couples capacity expansion and unit commitment / dispatch / power flow

Prior Applications:

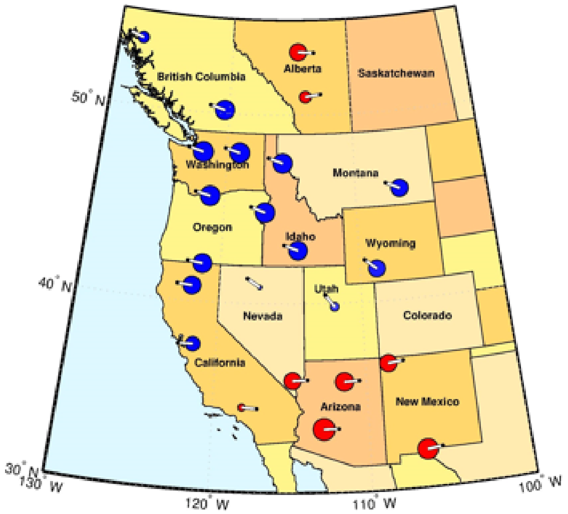
- Demonstration of benefits of both probabilistic and co-optimized expansion models, on exemplar WECC system
- Scalable HPC demonstration of co-optimization expansion model solvers
- Analysis of benefits of stochastic power grid operations, under DOE/ARPA-E and DOE/OE projects
- Model details informed by significant interactions with WECC and PJM
- Lab-developed (Sandia) tool; NREL is recent development partner
- Models are under active development and extension

Proposed Application to Resilience Modeling:

- Planning expansion under uncertainty to achieve specific resiliency goals
  - Expansion planning is universally focused on economics / reliability
- Integration of resiliency metrics and operational paradigms into production cost modeling
  - Assess alternative operational strategies for improved resiliency
- Requires HPC for practical (e.g., few-hour) turn-around times
- Uncertainty in renewables production, demand evolution, and policy are key inputs

Contact: Raymond Byrne, 505-844-8716, rhbyrne@sandia.gov

Small Signal Stability Analysis and Modeling



Visualization of WECC 0.37 Hz mode

Model details:

- Small signal stability refers to the response of the power system to small disturbances. Decreased mode damping results in reduced resiliency to grid disturbances
- Sandia has developed MATLAB tools that update dynamic simulation models (e.g., PSLF) with various renewable generation scenarios and then perform modal analysis on the dynamic simulation results

Prior Applications:

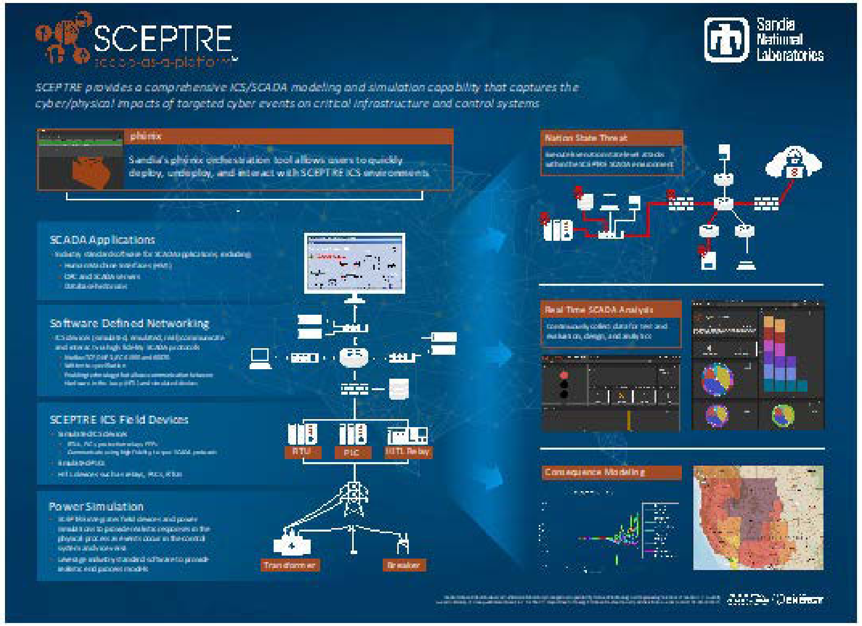
- Studies quantifying the impacts of large penetrations of renewable generation on small signal stability (e.g., WECC, NPCC)
- Control system design for a prototype PDCI damping control system
- The modal analysis GUI has been adopted by the WECC for visualizing mode shapes

Proposed Application to Resilience Modeling:

- Evaluation of small signal stability margins for future grid scenarios
- Design of control systems to improve small signal stability in large power systems

Contact: Raymond Byrne, 505-844-8716, rhbyrne@sandia.gov

SCEPTRE: SCADA-as-a-Platform



Model details:

Name: SCEPTRE

Type: Virtualized Emulation

SCEPTRE is unique by providing a cyber-physical interface to show how cyber-initiated events affect the physical world (and vice versa)

- Traditional SCADA test beds are burdensome
- Lab-scale hardware testing is insufficient
- Control network-only simulations are incomplete

SCEPTRE deploys live, operational environments that users can interact with. SCEPTRE is scalable, modeling the smallest of systems to large, interconnected systems (e.g., WECC). SCEPTRE environments can be built in rapid fashion and easily duplicated for parallel testing

Source: Sandia, DOE/DoD funded

Update/availability: GOTS; actively maintained with regular updates

Prior Applications:

- Current and prior sponsors include DoD, DOE/OE, DOE/IN, and other OGAs
  - Example deployments; CyberGuard/CyberFlag, J-BASICS
- Real-time end-process model simulations
  - Power systems, batch processes (e.g., oil/gas refinery, water treatment, etc.), rail control, pipeline
- Virtual control system field devices
  - PLC, RTU, protection relay, FEP, smart inverter
- Hardware-in-the-Loop (HITL) devices
  - Integrated for additional fidelity and realism where it's needed most (network and field devices)
- Custom and COTS SCADA applications
  - COTS products (e.g., GE EMS, Wonderware HMIs, etc.) can be integrated
- Software defined networking w/ to spec protocols
  - Virtual field devices talk SCADA protocols which are indistinguishable real devices on the network
- Map-to-Model (M2M)
  - M2M techniques being developed to quickly map an ICS environment (down to the field device level) and quickly deploy a replica SCEPTRE environment

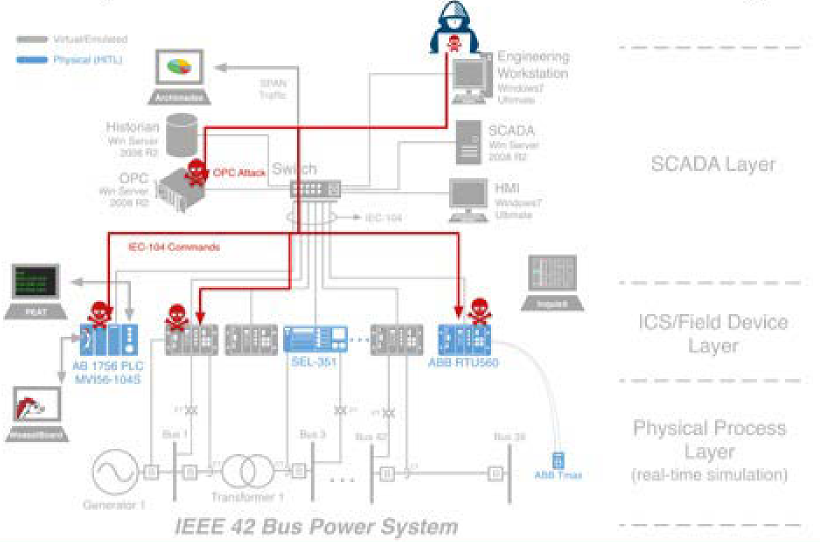
Proposed Application to Resilience Modeling:

- SCEPTRE allows you to quickly deploy and tear down ICS and SCADA environments for:
  - Testing TTPs
  - Research and development
  - Vulnerability and malware analysis
  - Training
  - Mitigation evaluation
  - Physical effects modeling
- High fidelity virtualized emulation
  - Running actual, to-spec ICS/SCADA network protocols
  - Near real-time (limited only by end process simulation)
  - Runs in virtual machines on commodity x86 cluster hardware, with extensive Hardware in the Loop support
  - Seamless composability with other models has been demonstrated at multiple levels

Contact: Brian Gaines, 505 845-7329 bgaines@sandia.gov

Instrumented ICS/SCADA Malware Analysis Testing Environment

Example: CRASHOVERRIDE Malware Analysis



Model details:

Name: Instrumented ICS/SCADA Malware Analysis Environment

Type: Hardware-in-the-Loop (HITL) with Virtualized Emulation

- Balance between fidelity (HITL), flexibility, and speed (rapid environment design and setup)
- Emulations permit parallel testing, rapid environment reset, and aggressive testing regimes without risk of ”bricking” devices
- Highly instrumented to provide deep introspection and data collection for post experiment analysis
- Evaluate “what if” scenarios and potential mitigations

Source: Sandia, DOE/DoD funded

Update/availability: GOTS; actively maintained reverse engineering and analysis environment

Prior and Current Applications:

- CRASHOVERRIDE
  - Rapid instantiation of sandboxed malware analysis environment (with HITL) CRASHOVERRIDE malware analysis. One of the first detailed dynamic studies of the malware, resulting in meaningful results and proposed mitigations.
- J-BASICS
  - Testing and evaluation of ICS TTPs assisting IT/OT personnel to detect, mitigate, and recover from nation-state level cyber threats.
- Field Device Assessment Methodology (FDAM)
  - Thorough vulnerability assessments at the field device level.
- Artificial Diversity and Defense Security (ADDSEC)
  - Development of moving target defense and dynamic defense technologies

Proposed Applications:

- TRISIS malware analysis
  - TRISIS malware analysis similar to previous studies, e.g. CRASHOVERRIDE
- Continued development and improvement of mitigation strategies
  - Improvement of ICS situational awareness tools (WeaselBoard, Archimedes, etc.)
- Predictive threat analysis with proactive results

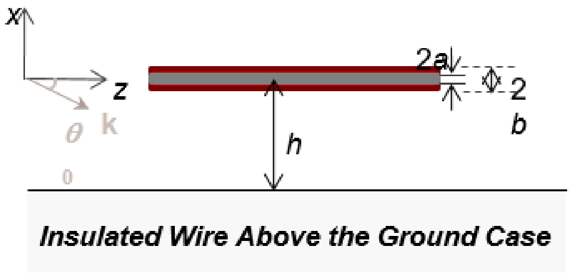
Proposed Application to Resilience Modeling:

- The Malware Analysis Testing Environment provides a sandbox for improving Sandia ICS capabilities against real world malware
- SCEPTRE
  - Comprehensive ICS/SCADA modeling and simulation capability that captures the cyber/physical impacts of targeted cyber events on critical infrastructure and control systems.
- Archimedes
  - Network-level ICS situational awareness tool, identifying trends and detecting anomalies in control system data signals
- PLC Extraction and Analysis Tool (PEAT)
  - Automate firmware, logic, and configuration extraction from ICS field devices for verification and indicators of compromise.
- WeaselBoard
  - Situational awareness at the field device level. WeaselBoard sits on PLC backplanes, examining communications between modules. Behavioral analysis enables detection of zero-days and other control system anomalies

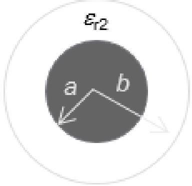
Contact: Brian Gaines, 505 845-7329 bgaines@sandia.gov

EM/EMP/GMD Modeling Capabilities

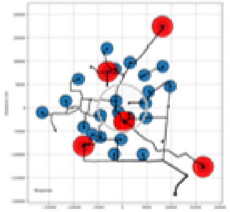
Analytic Transmission Line Over Ground (Atlog)



Insulated Wire Cross-Section



Xyce 6.8: xyce.sandia.gov



Model details:

ATLOG: analytical, frequency-domain and time-domain codes based on transmission line theory for electric utility grid; models EMP excitation of transmission line conductors, including coupling to lossy or perfectly-conducting ground or air; treats both insulated and bare, infinite and finite wires above-, on-, or under-ground.

Xyce: massively parallel circuit simulator (SPICE style) for coupled EM to transmission line modeling, including detailed device-level models (transformers, etc.). Capable of transient, AC, DC and harmonic analysis. Can include radiation aware devices models.

Prior Applications:

ATLOG: fast turnaround method: offered as an alternative option to a full-wave solution – useful to quickly assess a wide variety of scenarios and determine relative impact over a wide parameter space and is not limited in the length of the line; does not require an expert user and can be used in an operator-mode for damage assessment

Xyce: 46 transmission lines, 33 switching substations, 5 transformers

Proposed Application to Resilience Modeling:

ATLOG: to be used as a source building block for sections of the grid to calculate decay lengths of both common and differential modes of EMP coupling to transmission line infrastructure and calculate detailed coupling effects to switching, SCADA, and other devices within substations and switchyards

Xyce: to evaluate city-wide to regional scale electrical grid response to an EMP event, including transmission and distribution infrastructure; step-up, step-down, and switching substations; and transformers

Contact: Craig Lawton, 505-844-4895, crlawto@sandia.gov

System of Systems Analysis Toolset
Joint Operational Energy Initiative (JOEI)

Model details:

Name: System-of-Systems Analysis Toolset (SoSAT) / Joint Operational Energy Initiative

Type: Large-scale custom discrete event simulation code. System of Systems Analytic Toolkit provides an analytic framework for system of system trades

Source: Sandia, DOD sponsored development

Scope: Energy systems and subsystems (e.g., vehicles, energy generators/resources, energy infrastructure). Evaluates operational energy utilization in a large area of operations

Uncertainty: Explicit representation of uncertain/stochastic parameters (e.g., failure probabilities)

Implementation:

Prior Applications: Used by DOD to evaluate operational energy utilization in a large geographic area of operations (e.g., COCOM)

- Evaluates key energy (efficiency) technologies (e.g., storage technologies, renewables etc.)
- Evaluating fuel use benefits of key vehicle technologies (e.g., Auxiliary Power Units reduce fuel use over mission cycle)

Update/availability: 2018 software Version 3.0, documentation, model library and use cases, training. Extensive V&V by the DOD

Proposed Application to Resilience Modeling:

Proposed Scope: Model can be easily modified for application to more general energy domains/infrastructures for use as an energy resilience evaluation framework

Processes modeled: Simulates network, load, storage and generation elements and their respective failure rates and mechanism

Computational: Runs on PC/workstation. Supports parallel computing (cluster) environments for large scale analyses

Uncertainty: Explicit representation of uncertain/stochastic parameters (e.g., failure probabilities)

Contact: Craig Lawton, 505-844-4895, crlawto@sandia.gov

Facilitated Small Group Discussions

Facilitated discussion on data, tool, and training priorities

- In small groups, discuss where additional tool training or investment is needed to address Puerto Rico stakeholder needs for long term stability of electric system
- Choose a group member to write down priority topics and post on the wall
- Goal is to get top 2-3 needs on data and tools and 1-2 priorities for DOE related to that space
- Possible group table topics are:
  - Solar resource data (how to get it, what it's going to look like after phase 2) – with Nate
  - Facilitation of Distributed Energy Resources (DERs) on the grid (residential) – with Dan
  - Microgrids, resilience, and critical infrastructure – with Rob
  - Energy efficiency – with Adam
  - Training needs and local capacity – with Elaine
  - Finance – with Elaine
  - Community-oriented solutions – with Robin

Report-Out from Discussion

- Facilitators and participants report out on top priorities
- Participants go around the room and put dots on their top priorities

Next Steps

Report-Out from Discussion

- Discussion focused on:
  - Potential solutions
  - Available resources
  - Making connections

Concurrent Afternoon Sessions

- **Option 1. System Advisor Model (SAM) User Group Session**.
  This three-hour, hands-on session provides an overview of SAM and related tools and solicits feedback from users on Puerto Rico specific needs. Also covers the National Solar Radiation Database (NSRDB), PVWatts, Utility Rate Database, Jobs and Economic Development Impacts (JEDI) tool and other relevant data and tools. Suitable for anyone interested in individual system simulations.
- **Option 2. HEVI and MAFRIT/FESTIV Tools Overview and Discussion**.
  Learn more about NREL's capacity expansion modeling tool Hawaii Energy Visualization Initiative (HEVI), and grid modeling tools Multi-Area Frequency Response Integration Tool (MAFRIT) and Flexible Energy Scheduling Tool for Integrating Variable Generation (FESTIV) in this three-hour session.
- **Option 3. Energy Efficiency Tools and Resources**.
  Attend this session for a more in-depth discussion on energy efficiency needs in Puerto Rico and available resources.

Thank You!

NREL/PR-6A20-73835

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